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PROPULSION ENGINEERING RESEARCH CENTER

1993 ANNUAL REPORT

VOLUME I

NOVEMBER, 1993

A UNIVERSITY SPACE ENGINEERING RESEARCH CENTER

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UNIVERSITY PARK, PENNSYLVANIA 16801

PROPULSION ENGINEERING RESEARCH CENTER

NASA UNIVERSITY SPACE ENGINEERING RESEARCH PROGRAM

ANNUAL REPORT

for the period
November 1, 1992 - October 31, 1993

VOLUME I

The Pennsylvania State University
University Park, PA

PROPULSION ENGINEERING RESEARCH CENTER
1993 ANNUAL REPORT

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EXECUTIVE SUMMARY

Over the past year, the Propulsion Engineering Research Center at The Pennsylvania State University has continued its progress toward meeting the goals of NASA's University Space Engineering Research Centers (USERC) program. The USERC program was initiated in 1988 by the Office of Aeronautics and Space Technology to provide an invigorating force to drive technology advancements in the US space industry. The Propulsion Center's role in this effort is to provide a fundamental basis from which the technology advances in propulsion can be derived. To fulfill this role, we have developed an integrated program that focuses research efforts on key technical areas, provides students with a broad education in traditional propulsion-related science and engineering disciplines, and provides minority and other under-represented students with opportunities to take their first step toward professional careers in propulsion engineering. The program is made efficient by incorporating government propulsion laboratories and the US propulsion industry into the program through extensive interactions and research involvement.

The Center is comprised of faculty, professional staff, and graduate and undergraduate students working on a broad spectrum of research issues related to propulsion. The Center's research focus encompasses both current and advanced propulsion concepts for space transportation, with a research emphasis on liquid propellant rocket engines. The liquid rocket engine research includes programs in combustion and turbomachinery. Other space transportation modes that are being addressed include anti-matter, electric, nuclear, and solid propellant propulsion. Outside funding supports a significant fraction of Center research, with the major portion of the basic USERC grant being used for graduate student support and recruitment. The remainder of the USERC funds are used to support programs to increase minority student enrollment in engineering, to maintain Center infrastructure, and to develop research capability in key new areas. Significant research programs in propulsion systems for air and land transportation complement the space propulsion focus.

The primary mission of the Center is student education. The student program emphasizes formal classwork and research in classical engineering and science disciplines with applications to propulsion. Twenty-one students from the Center with advanced degrees and research backgrounds in propulsion-related graduated during the present reporting period. Thirty-one students from the Center have started careers at US government propulsion laboratories and in the US propulsion industry since the Center's inception. Undergraduate students are also involved in the Center's research program throughout the year. A special summer undergraduate program that brings minority students into Center laboratories to work on research projects alongside Center students and faculty has been developed and occurs annually. The number of well-qualified US students who wish to pursue graduate research at the Center continues to grow, even though the current short-term outlook for permanent employment opportunities in space transportation is poor. We are taking innovative measures to ensure that talented US students who want to work in the propulsion field can fully benefit from the strong research and education programs that have been established at the Center.

Significant Events and Achievements of the Past Year

Externally-Funded Research programs over the past year increased to 36, a substantial increase from 21 in the prior year. In addition to the base USERC grant, research is sponsored by the Marshall, Lewis and JPL field centers, by the Army, Navy, and Air Force, and by the industrial community. The major US rocket engine contractors, Aerojet, Pratt and Whitney, Rocketdyne, and TRW, are all working directly with Center faculty and students on research projects that will lead to improvements in their propulsion technologies. The Center's success in attracting outside funding is a major indicator of the impact it has had on the propulsion community, and on the high regards the community has for research performed by faculty, staff, and students of the Center.

EXECUTIVE SUMMARY

The Center's *Minority Program* continued its emphasis on encouraging women and minorities to pursue careers in engineering. The past year, the Summer Undergraduate Program, which is the Center's main organized minority effort, included four participating minority students from four different universities across the country. The Center has stepped up its efforts to increase minority participation in propulsion-related efforts at the graduate level by initiating a program with selected universities and colleges with high minority populations.

The *Cryogenic Laboratory*, the cornerstone of the Center's experimental program, is in routine operation mode and is presently being used to produce experimental data for several research projects. This major resource was completed on schedule and within budget in 1992. Quantitative measurements in high-pressure, hot-fire research combustors have been made, including two-dimensional images of OH concentrations, heat flux measurements, propellant drop and gas velocity measurements, and the first quantitative measurements of LOX drops ever made in a rocket environment.

The *NASA Seminar Series*, designed to enhance the interactions between the Propulsion Center and the space propulsion community, continued into its third year. Speakers from the Langley, Lewis, Marshall, Kennedy, Stennis, and Johnson Centers, the Jet Propulsion Lab, NASA Headquarters, the Air Force Phillips Laboratory, and the US Congress have lectured on technical and social issues of import to the US space program. The Seminar Series has been highly successful, and has proven to be a highlight experience for faculty, students, and speakers alike. Six speakers visited the Center in this reporting period.

Community Interactions remained strong, as evidenced by the broad research support noted above and by Center visits from representatives of the various NASA Centers, the Air Force, all major US engine contractors, and several international corporations and laboratories. The Center was the host for the First International Symposium on Liquid Rocket Engine Combustion Instability in January, 1993, with papers presented from representatives from the US, Russia, The Ukraine, Japan, China, Taiwan, Germany, and France. Other interactions over the last year included numerous technical presentations at national and international conferences; publications in refereed technical volumes; public service through active participation on national technical committees, panels, and consortia; and most importantly, career placement of Center students throughout the propulsion community. Eight graduates from the Center with advanced degrees started their professional careers in propulsion-related areas over the past year.

The *Fifth Annual Symposium* was held at Penn State in September. The Center's Symposium has developed into one of the premier technical meetings on space propulsion in the world, with over 100 registered attendees participating in this year's meeting representing government laboratories, NASA headquarters, small business contractors, and all the major rocket engine contractors. Forty-three papers were presented, with approximately half of the presentations being done by students from the Center. The Sixth Annual Symposium is scheduled to be held at the Lewis Research Center in September, 1994.

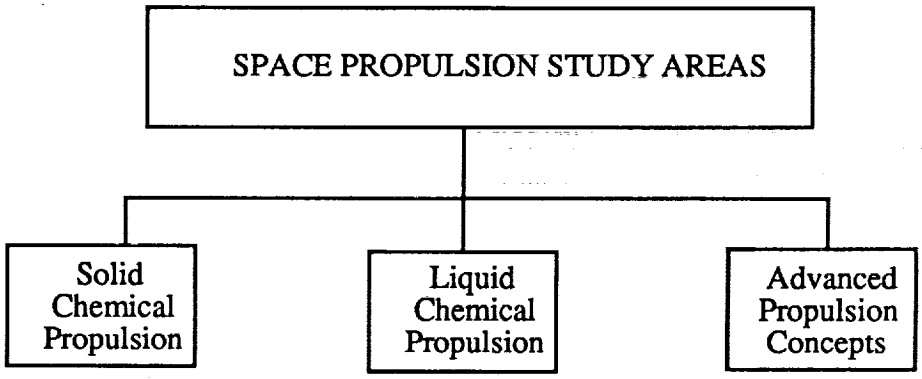
K-12 Outreach continued through faculty presentations to primary and secondary students, laboratory tours by students enrolled in special math and science programs, participation in special events on the Penn State campus oriented toward primary and high school students as well as alumni, and sponsorship of high school students enrolled in the Space Academy at Penn State. The Center has also continued its support of K-12 planning activities at NASA Headquarters.

PROPULSION ENGINEERING RESEARCH CENTER
1993 ANNUAL REPORT

I. INTRODUCTION

The Propulsion Engineering Research Center at The Pennsylvania State University was established in August, 1988 by a grant from NASA's University Space Engineering Research Center (USERC) program. The USERC program was initiated by the NASA Office of Aeronautics and Space Technology to replenish and enhance the capabilities of our Nation's engineering community to meet future space technology needs. The Propulsion Engineering Research Center is focused on space propulsion with research emphases in three areas: liquid chemical propulsion, solid chemical propulsion, and advanced propulsion concepts (Fig. 1). Of these three areas, the primary emphasis is on liquid propulsion.

FIGURE 1. RESEARCH PROGRAM STUDY AREAS



To meet the USERC program goals, the Center's objectives are: (1) to provide a continuing supply of graduates at all degree levels for the propulsion community; (2) to conduct focused research that will lead to improved technologies in propulsion; (3) to enhance participation in engineering by both women and under-represented minorities; and (4) to develop a basis for self-sustenance. Our general approach toward achieving these objectives has been to develop a broadly-based research program that will attract US students to study at the Center and US government laboratories and propulsion contractors to fund Center research. Key strategies in this plan are:

- Enhance a diverse and fundamental research program oriented toward space propulsion applications;
- Develop and maintain well-equipped experimental and computational laboratories;
- Offer a well-integrated selection of propulsion-based and propulsion-related courses at both the undergraduate and graduate levels; and
- Provide support for an integrated core of students and research staff to study a wide scope of propulsion-related problems.

The Center's success in meeting its objectives is clearly indicated. An excellent group of students have come to the Center to continue their graduate studies in propulsion-related sciences. There are currently 87 graduate students and 24 undergraduate students participating in research. Thirty-one

students with advanced degrees have gone from the Center to the US propulsion community as permanent employees. More than 70% of the graduate students are US citizens. A successful minority program to enable under-represented students to begin their careers in space propulsion has been developed and innovations to increase the efficacy of this program are being implemented.

The Center has become an important part of the propulsion industry in the US. Cooperative research efforts are underway with all the major US government rocket propulsion agencies and all the major US liquid propulsion contractors through funded research projects. The Center is a major resource for the propulsion community providing both a basis for technological advancements and science and engineering graduates with a sound and broad background to work on the technical challenges of space and air transportation.

The present document has been prepared to describe the present status of the Propulsion Engineering Research Center and its progress over the period from November 1992 through October 1993. In Volume I, an overview of the Center's organization is presented along with information on the Center's current status and accomplishments over the present reporting period in three areas that are tied to our primary objectives - Education, Propulsion Community Interactions, and Research. Appendices in Volume I include listings of technical subprogram areas and auxiliary sources of support, faculty and student involvement, and current publications and presentations. Volume II of this report contains the Proceedings of the Propulsion Engineering Research Center's Fifth Annual Symposium, where detailed information on current research at the Center may be found.

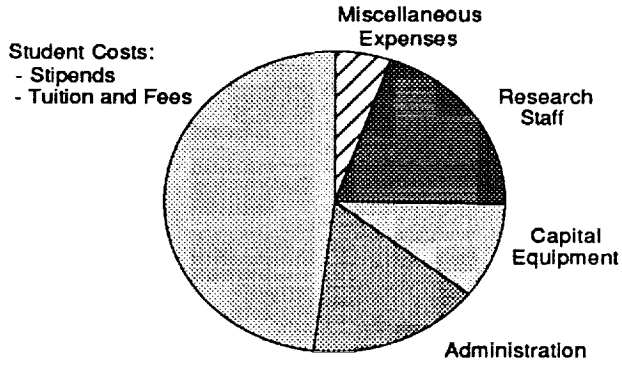
II. CENTER ORGANIZATION

The Center is comprised of an integrated group of students, faculty, and staff who are conducting fundamental research on a diverse set of problems related to propulsion. The organizational structure of the Center is outlined in Table 1. The USERC program is managed through NASA's Office of Advanced Concepts and Technology. The Center Director acts as Principal Investigator, and is generally responsible for the Center. The Director is aided by the Associate Director, the Assistant Director, and the Administrative Coordinator in developing and implementing policies and strategies for research and education.

The Center's Policy Advisory Board is made up of propulsion experts from NASA, industry and academia. This group is charged with helping to guide long range development to ensure that the Center can capably respond to the nation's space propulsion technology needs. The Policy Advisory Board met twice during the present reporting period to evaluate the overall progress of the Center from an objective, external viewpoint, and to advise in matters of policy and research emphasis. The Technical Review Committee is composed solely of NASA personnel, and represents NASA Headquarters and the Lewis, Marshall, and Jet Propulsion Laboratory field centers. The Technical Review Committee meets once per year to evaluate the Center's progress and to make recommendations regarding the Center to the Director and to the USERC Program Manager.

A primary function of the Center Director is to allocate USERC funds according to Center objectives. A breakdown of the actual distribution for 1993 is shown in Figure 2. As has been the case in previous years, funding for students remains the dominant recipient of USERC funds. This distribution of USERC funds reflects the primary USERC objective - student education. Funds allocated to students include direct student support in the form of NASA traineeships and research assistantships, as well as the payment of tuition and fees. While approximately half of the Center funds go directly to student support, most of the remainder indirectly supports the student program via administration, equipment purchases for student research, and salaries for experienced staff to help faculty direct student research.

FIGURE 2.
THE USERC GRANT IS USED PRIMARILY FOR COSTS OF STUDENT EDUCATION



Direct student support along with an excellent research program are effective means to recruit well-qualified students. The Center's reputation has led to a steady increase in both the number and quality of the applicants to our graduate programs. The Center's long term funding has enabled us to commit support to outstanding students early in the recruiting year, while providing the student a selection of project and technical areas in which to work. As a result, the Center has been able to attract some of the very best students in the US. Similarly, the USERC grant has enabled the acquisition of major research equipment that aids in the quality and relevance of our research efforts. Our quality equipment and facilities have also been a major factor in student recruitment. Finally, the USERC grant has impacted both student recruitment and student education through enabling us to assemble a core of experienced research staff to help guide students in their research, and to provide support to maintain a small but effective administrative infrastructure.

In terms of research structure, USERC funds also serve to establish the direction and focus of the Center's research program. Funds from the USERC grant are used to ensure that the Center's research efforts are integrated and mutually synergistic. The Center program is also designed to

Table 1. Organization and Management Structure

USERC PROGRAM MANAGEMENT

Dr. Robert Hayduk, USERC Program Manager,
Office of Advanced Concepts and Technology, NASA Headquarters

CENTER ADMINISTRATION

Professor Charles Merkle, Director and
Distinguished Alumni Professor of Mechanical Engineering
Professor Robert Santoro, Associate Director and
Professor of Mechanical Engineering
Mr. William Anderson, Assistant Director
Mr. John Raiser, Administrative Coordinator

POLICY ADVISORY BOARD

Dr. Jim A. Clark, Group Leader, Combustor and Augmentor Design,
Pratt & Whitney
Dr. Robert Corley, Chief Scientist, Propulsion Directorate,
Air Force Phillips Laboratory
Dr. Larry Diehl, Chief, Space Propulsion Technology Division,
NASA Lewis Research Center
Mr. Stephen Evans, Director of Advanced Technology Programs,
Rocketdyne Division, Rockwell Corporation
Mr. Robert Sackheim, Deputy Director of Propulsion and Fluid Mechanics Center,
TRW Corporation
Dr. Adam Siebenhaar, Manager, Space Propulsion Programs,
Aerojet Propulsion Division, GenCorp
Professor Warren Strahle, Regent's Professor of Aerospace Engineering,
Georgia Tech University
Mr. George Young, Deputy Chief, Component Development Division,
NASA Marshall Space Flight Center

TECHNICAL REVIEW COMMITTEE

Mr. William Escher, Technical Review Committee Chair, Earth to Orbit Program Manager,
Office of Advanced Concepts and Technology, NASA Headquarters
Dr. Philip Garrison, Manager, Propulsion and Chemical Systems Section,
NASA Jet Propulsion Laboratory
Mr. John McCarty, Chief, Propulsion Laboratory, NASA Marshall Space Flight Center
Dr. Larry Diehl, Chief, Space Propulsion Technology Division,
NASA Lewis Research Center

accommodate development of the necessary attributes of a successful University Research Center - *depth* in a specific research area to develop research excellence and synergy between projects, and *breadth* to provide students with exposure to a variety of opportunities and to enable the Center's response to a wide variety of applications of interest.

Program depth is focused on critical technology aspects of liquid rocket propulsion systems related to combustion devices and turbomachinery. Complementary research areas related to space transportation include advanced propulsion concepts and solid propellant propulsion. Coupled to the space propulsion research is work in related propulsion areas including gas turbines, diesel engines and internal combustion engines. This work has proven to be a strongly synergistic source for the development of the Center, as well as forming a major portion of the Center. Since these programs receive none of the USERC funds, they are not discussed in detail in the present report.

Taken as a whole, these propulsion areas, including both space and terrestrial transportation modes, serve to expose our students to a wide spectrum of propulsion applications. This grouping of topics provides a balanced view of propulsion to our students, faculty, and visitors alike that includes both breadth and depth.

A final aspect of the Center's structure is the continuing support from the University. The University continues to pay half the administrative costs of the Center and provide matching money on major equipment purchases. The University has also been generous in providing research space. We presently occupy three-quarters of a modern research building (the entire first floor, part of the second, and all of the lower level). These co-located offices and laboratory have been an essential ingredient in the Center's progress by enhancing interactions between students and faculty. A remote test site was also allocated and refurbished by the University to allow the development of the Cryogenic Combustion Laboratory, which is a key component of the Center's research program. Lab and office space allocated to the Center presently stands at about 18,000 square feet. Additional University support includes fellowship awards to several Center students and overhead sharing.

III. EDUCATION

The primary goal of the Propulsion Center is to provide graduates at all degree levels who have interests and capabilities in space propulsion and related engineering sciences. Accordingly, a major effort has been made to attract the very best students to learn and work in the Center. An active and visible research program in an exciting technical area and a highly respected faculty are the primary requisites for attracting top quality students. Space propulsion has proven to be an area of particular interest to students. In addition, we have chosen a strong cadre of faculty for staffing the Center. Other positive attributes include the visibility provided by the presence of the Center, the modern, well-equipped experimental and computational laboratories that have been obtained through the Center, and the attractive physical plant which has been provided by the University because of the Center. The students that have been attracted to our program as a result of these combined attributes are a convincing, visible demonstration of the Center's effectiveness.

The faculty and students that comprise the Center are drawn from the College of Engineering and the College of Science. In the College of Engineering, the Departments of Aerospace Engineering, Engineering Science and Mechanics, Mechanical Engineering and Nuclear Engineering are involved, while the Department of Physics represents the College of Science. Thirteen faculty from these Departments directed research projects at the Center over the present reporting period.

The faculty in the Center participate as Principal Investigators on the Center's research projects and are active in bringing External and Matching Projects to the Center. Quite naturally, the faculty represent the permanent core of the Center's capabilities. They work individually with the Center students as research advisors, providing specialized training in propulsion-related research projects for all students. In addition, Center faculty provide formal instruction in propulsion-related classroom and laboratory courses. Finally, the faculty as individuals and as a group attract numerous visitors from outside the University to the Center, thereby providing the students with invaluable interactions with internationally known propulsion experts on applications both related to and outside the students' specific fields of study. This interaction with outside experts occurs to a degree that the students could not possibly experience apart from the Center. These various attributes of the Center make it possible for us to realize our foremost goal: the continued production of outstanding graduates.

The primary focus of the Center's educational program is at the graduate level. These graduate activities are augmented by a significant involvement of undergraduate students as well. Our graduate students come from undergraduate programs widely dispersed across the United States, as well as from countries around the world. The major emphasis in the graduate program is at the PhD degree level, although the Center also includes a significant number of students at the MS level.

Students are able to choose from a wide and deep selection of courses in propulsion offered through the Mechanical and Aerospace Engineering departments at Penn State. Since the Center's inception, four new propulsion courses have been added. Table 2 lists the courses directly related to propulsion engineering. This course selection, taught by faculty with demonstrated research excellence in their respective areas, is a prime attraction for students considering graduate school.

The Center's effectiveness in graduate student recruiting has had a major impact on propulsion-related research performed at Penn State and on graduate student enrollment in both the Aerospace and the Mechanical Engineering Departments. Eighty-seven graduate students worked on research projects in air, land, and space propulsion applications in the present reporting period. The quality of these students, as judged by both GPA's and GRE scores, continues to be very high. In addition, the students demonstrate excellent communication skills, partially because the Center setting and its many external visitors provide them with ample opportunity to use and enhance these skills.

Table 2. Propulsion Courses

MECHANICAL ENGINEERING

403. Rocket Propulsion. Design and performance of rocket propulsion components and systems; thermodynamics, solid and liquid fuels, heat transfer, materials, controls, and instrumentation.

409. Gas Turbines. Thermodynamic cycles relating to gas turbines; analysis and performance of compressors, combustion chambers, single- and multi-stage turbines; recent developments.

418. Principles of Turbomachinery. Application of Newton's laws of motion and basic laws of thermodynamics to analysis of fluid flow in turbomachinery.

516. Combustion in Propulsion Systems. Theoretical formulations and methods of solution of engineering problems and physical processes in chemical propulsion systems.

597. Advanced Chemical Rocket Propulsion. Modern aspects of chemical rocket propulsion systems, with special attention focused on liquid-propellant rocket systems. Topics include combustion and burning characteristics of propellants; performance and heat transfer analysis; component design, and combustion instability.

AEROSPACE ENGINEERING

410. Aerospace Propulsion. Analysis and performance characteristics of reciprocating engine, turbojet, turboprop, turbofan, ramjets, and chemical rockets. Aerothermodynamics of inlets, combustors, and turbomachinery.

430. Space Propulsion and Power Systems. Analysis and performance of chemical and nuclear rockets, electric propulsion systems. Introduction to solar, chemical, thermoelectric, and nuclear power sources.

507. Theory and Design of Turbomachinery. Theory and principles of machinery design: compressors, turbines, pumps, and rotating propulsors; opportunity to work out design examples.

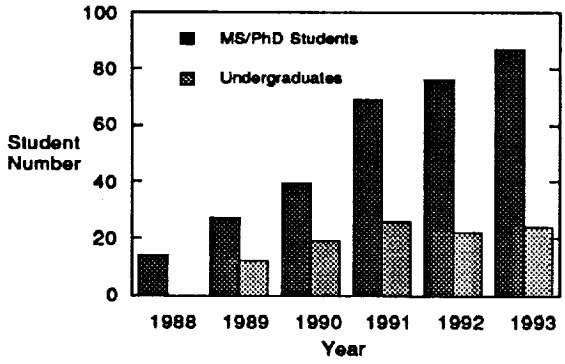
529. Advanced Analysis and Computation of Turbomachinery Flows. Review of numerical methods; three-dimensional inviscid flow computation, two- and three dimensional viscous flow effects and computation; recent advances.

530. Aerothermochemistry of Advanced Propulsion Systems. Basic physics and chemistry needed to analyze advanced rocket propulsion systems including reacting high temperature radiating gas and plasma flows.

597. Thermal Aspects of Propulsion. Topics from advanced fluid dynamics, heat transfer, computational methods and advanced experimental methods pertinent to air breathing and rocket propulsion, heat transfer in hypersonic flow and re-entry, and cooling schemes for propulsion systems.

Graduate students in the Center are supported in two ways. NASA Traineeships are funded out of the USERC grant and provide fellowship support for students having exceptional academic records and strong potential for performing high quality research. Three new Trainees were added in the past year. Research Assistantships are funded either through Matching Projects or directly through the Center grant. Over the present reporting period, 29 students were supported directly by the USERC grant, including 14 NASA Trainees and 15 Research Assistants. An additional 58 Research Assistants were supported by external contracts that funded research at the Center over the last year. Sixty-eight of these 87 graduate students are co-located in the Center's central facility, giving additional impetus for synergism among students and research projects. The Center is having a particularly significant impact in increasing enrollment of PhD students who are US citizens, with 63 of the 87 students being US citizens.

FIGURE 3.
STUDENT PARTICIPATION CONTINUES TO GROW



The history of student enrollment in the Center is shown in Fig. 3. Graduate student enrollment has continued to grow each year. The rapid initial growth was largely due to the four to five years it takes to complete a PhD program. It was expected that after 1992, the number of graduate students would remain between 70 and 80 students, and that undergraduate student levels would remain at around 25 students. However, the number of qualified students with interests in propulsion coupled with the increase in outside funding for research resulted in increased student numbers again in the last year.

In addition to these 87 graduate students and 24 undergraduate students supported either directly by the NASA USERC grant or by externally-funded projects, a significant number of others are affiliated with the Center through complementary propulsion research projects (gas turbines, internal combustion and diesel engines). A complete listing of students working on Center projects is provided in Appendix B.

Center students receive formal classroom education and specialized training through research, but they also have abundant opportunity to attend seminars given by invited speakers who are recognized experts in the propulsion field. A very successful aspect of the Center's educational program is the NASA Seminar Series, which has been very important in making the students aware of the practical technology aspects of their research, as well as career opportunities in propulsion.

Under the NASA Seminar Series, representatives from various NASA locations come to the Center and typically spend a full day interacting with students and faculty. A representative day includes an overview of the Center's projects, status, and goals, informal discussions with faculty and student groups, and laboratory tours and demonstrations. A special highlight is a lunchtime round table discussion between the NASA visitor and a group of six to eight students.

The NASA Seminar speaker presents a seminar on a topical issue of interest in space propulsion. The seminars are intended to give students and faculty alike an exposure to "real-world" concerns ranging from social to programmatic to technical issues. The seminars also serve to familiarize students and faculty with NASA capabilities and potential career opportunities. Speakers in this series to date have represented Lewis, Marshall, Kennedy, Stennis, Johnson, Langley and Headquarters as well as the Air Force Phillips Laboratory and the US Congress. A list of seminars that occurred over the present reporting period is provided in Table 3.

Table 3. 1992-93 NASA Seminar Series Speakers

• November 4, 1993	Mr. Mark Fisher, Marshall Space Flight Center "Saturn and Shuttle Boosters"
• September 10, 1993	Mr. William Knuth, The University of Tennessee "Full-Flow, Staged Combustion Rocket Engines"
• September 8, 1993	Mr. Richard Ryan, Marshall Space Flight Center "Results from NASA's Access to Space Study"
• April 28, 1993	Mr. Dennis Bushnell, NASA Langley Research Center "Hypersonic Airbreathing Propulsion - Research and Applications"
• March 31, 1993	Astronaut Guy Bluford, Johnson Space Center "Space Transportation - An Astronaut's Perspective"
• January 15, 1993	Mr. Gerald Pitalo, Stennis Space Center "Propulsion Activities at the Stennis Space Center"
• October 19, 1992	Mr. James Kelly, Jet Propulsion Laboratory "Nuclear Electric Propulsion for Planetary Missions"

Undergraduates are involved in the propulsion program through their participation in our research efforts and through classroom teaching by Center faculty. Undergraduate research involvement is fostered by a summer undergraduate program that is open to students from all universities, while Penn State undergraduates are involved at the Center throughout the school year. Bringing undergraduates into the Center to assist in research is an effective way of encouraging them to consider careers in propulsion. In the present reporting period, a total of 24 undergraduates were involved in research at the Center. Each undergraduate is assigned an individual faculty adviser and a graduate student mentor. Each undergraduate then works on a particular research project alongside the graduate student to improve his or her grasp of classroom activities, as well as to provide them with a first-hand glimpse of graduate school and advanced degree programs.

The Minority Program has been a highlight of the Propulsion Center's educational program. The USERC grant has enabled us to develop and maintain a successful minority program that has had positive results on several fronts. The Summer Undergraduate Program is the main element of the Center's minority program and is an effective way for the Center to help in recruiting under-represented groups into space propulsion engineering. This program enables minority students to begin their specialized studies in propulsion-related fields. Minority students from across the US are involved. This program has been augmented since 1991 by the College of Engineering Center for Undergraduate Research Opportunities (CURO) program since 1991, an NSF-supported program that was modeled after the Center's summer program. The Summer Undergraduate Program is concluded by a symposium where students give individual presentations of their research to their peers and advising faculty.

A list of the minority undergraduate students who participated in the 1993 Summer Undergraduate Program is provided in Table 4, along with their research topics and faculty advisors. A list of students who have participated in the Summer Undergraduate Program since the start of the Center is provided in Appendix B.7.

Faculty and students at the Center also interact with primary and secondary students through K-12 outreach programs. These interactions are in the form of presentations to youth groups and grade school students, an annual Open House for high school students interested in engineering, participation in the annual High School Student Intern Program in Engineering and Technology, and laboratory tours for the State College High School Science Club. The Center also supported the NASA Office of Aeronautics and Space Technology in preparing brochures and videos oriented to high school students. This year, a special group of "students" visited the Center as part of the Alumni College program, where Penn State alumni and family spend one week at the University Park campus to attend classroom-style lectures. The group of 20 who "studied" at the Center ranged in age from school-children to grandparents. The Propulsion Center was one of the more popular sites, and the Alumni College organizers have requested the Center's participation again in 1994.

Table 4. 1993 Summer Undergraduate Program

Name	Major/University	Research Topic
Ecton English	Mechanical Engineering University of Maryland	"Atomization Measurements in Impinging Jet Injector Elements"
Desmond Miller	Aerospace Engineering Penn State Berks Campus	"Distributed Parallel Processing on Workstation Networks"
Jabbar Thomas	Physics Morehouse University	"Effects of Variable Properties in Turbulence Modeling"
Jaime Vasquez, Jr.	Physics Lincoln University	"Atomization Measurements in Coaxial Injector Elements"

IV. PROPULSION COMMUNITY INTERACTIONS

The Center's interactions with the US propulsion community have been very strong from the outset. As the Center grows and matures, so these interactions continue to grow and mature in a substantive way. Interactions occur in a variety of forms, including placement of Center graduates in government laboratories and in industry; Annual Symposia; participation on the Policy Advisory Board and in the NASA Seminar Series; externally-funded research grants and contracts; participation in graduate programs by full-time NASA employees; publications in technical journals and presentations at technical meetings; participation in numerous planning groups, advisory panels and workshops; and as editors of propulsion journals. Some of the highlights of these interactions are described below.

Our most important interaction with the propulsion community is one that will have a dominant long-term impact - the placement of our graduates in permanent employment positions in the industry. Since the Center's inception, 31 students with advanced degrees have commenced their professional careers in the US propulsion community, either in industry or at government laboratories. NASA employees include three Center students at Lewis Research Center, three at Marshall Space Flight Center, one at Jet Propulsion Laboratory, one at Ames Research Center, and one at Langley Research Center. Students have also been placed with industrial propulsion employers, including Rocketdyne, Pratt and Whitney, UTRC, Martin Marietta, Fluent, CFD Research, Lockheed, Aerospace Corporation, General Electric, Allison, and Westinghouse. Three Center students are participating in the Air Force Palace Knight program at Phillips Laboratory, where they will commence their professional careers after graduation. Table 5 lists the students who graduated during the present reporting period, their degrees, and their current place of employment. Appendix B contains a summary of all students from the Propulsion Engineering Research Center who have gone on to careers in the US propulsion community and elsewhere.

As a complement to these students that have graduated and have been placed in the propulsion community, employees from NASA and the Air Force have taken advantage of the presence of the Center to return to school to obtain advanced degrees. One employee each from Marshall Space Flight Center, Lewis Research Center, and Johnson Space Center, and two employees of the Air Force were enrolled in the graduate program during the present reporting period. Marshall Space Flight Center is also supporting four students through the Graduate Student Researcher Program.

The Center's Annual Symposium is a formal avenue through which the Center disseminates its technical findings and interacts with the external propulsion community. The Annual Symposium is rotated between three locations: our own facilities at the Propulsion Engineering Research Center in University Park, the NASA Lewis Research Center in Cleveland, and the NASA Marshall Space Flight Center in Huntsville. This gives both our students and employees at the two primary NASA propulsion centers opportunity to interact with each other on a regular basis, while minimizing travel constraints and meeting duplications. The Center's Symposia have developed into one of the premier annual meetings on space propulsion engineering and science, with its value enhanced by the three-way site rotation between Penn State and the Lewis and Marshall centers of excellence in propulsion. The first cycle of the three-way rotation was completed at Penn State this year.

The Fifth Annual Symposium was held at the Penn State campus on September 9-10, 1993. The covered topics included:

- steady state combustion,
- combustion stability,
- heat transfer and fluid mechanics,
- turbomachinery, and
- advanced propulsion concepts.

A total of 43 papers were presented, representing contributions from academia; industry; and NASA, DOE, and Air Force laboratories. Twenty-two of these papers were given by students of the Center who presented results from research ongoing at the Center in space propulsion. The invited talk was by Mr. Richard Ryan of Marshall Space Flight Center who presented results from NASA's *Access to Space* study, with a

focus on the Advanced Technology Replacement option of that study. One-hundred and twenty registered participants attended the Symposium. The Sixth Annual Symposium is planned to take place at Lewis Research Center in September, 1994.

Table 5. 1992-93 Graduates

Name	Degree	Current Employment
Barry Fetherolf	PhD	Martin Marietta
Christopher Gazze	MS	USAF
Eric Hornchek	MS	XiLinx
Simon Leonard	MS	Rolls-Royce, Canada
Douglas Leone	MS	Southwest Research Institute
Peter Liiva	MS	Texaco Fuels and Lubricants Laboratory
Norman Lin	PhD	Chung Shan Institute of Science & Technology
Lynn Medvetz	MS	SKF
Jennifer Miller	PhD	NASA Langley Research Center
David Nye	PhD	Allison Gas Turbines
Jih-Ping Peng	PhD	Seagate Technology
Rahul Puri	PhD	Allison Gas Turbines
Thomas Richardson	PhD	Allison Gas Turbines
Eric Roll	PhD	PSU Faculty, Behrend Campus
Scott Sheffer	MS	Research Assistant, Princeton University
Michael Surratt	PhD	Air Force Phillips Laboratory
James Withington	PhD	Boeing
Roger Woodward	PhD	Air Force Phillips Laboratory
S.-R. Wu	PhD	Research Associate, Propulsion Engineering Research Center
Andrew Yang	PhD	Earth Satellite Propulsion Division, Taiwan
David Yoset	MS	Stone & Webster Engineering

Besides the Symposium, research results from the Center program are disseminated to the propulsion community by presentations at technical meetings, and through publications in appropriate journals. Center faculty have been very active in this area with 23 publications in refereed journals and edited volumes and 97 presentations made at professional conferences in the last reporting period. A cumulative list of publications, as well as special mentions, honors, panel participations, and presentations made by Center faculty and students in the present reporting period is provided in Appendix C.

On January 18-20, 1993, the Center hosted The First International Symposium on Liquid Rocket Engine Combustion Instability. This meeting was a unique and landmark event, and was attended by the world's leading experts in the field. Representatives from Germany, France, The Netherlands, The Ukraine, Russia, The People's Republic of China, Taiwan, Korea, and the United States were present. Especially noteworthy were presentations by representatives of countries from the former Soviet Union and from China. A significant amount of previously unreleased detailed technical information was presented by the Russians and Chinese. Researchers from NASA laboratory groups working in combustion instability made three presentations at the meeting, and research groups from the Propulsion Center made four presentations. Proceedings from the

Symposium will be published as an AIAA Progress in Astronautics and Aeronautics Series volume with Center faculty serving as co-editors. The success of the First International Symposium has led to plans to convene the Second International Symposium on Liquid Rocket Propulsion in France in June 1995. The general topic of the next symposium will be steady-state thermal processes in liquid rocket engines.

Another distinct interaction between the Propulsion Center and NASA, the Air Force, and industry is through the Policy Advisory Board in which all these groups are represented. We have an outstanding group of individuals on our board who have been very active and very effective. The Policy Advisory Board convened twice in the past year: a formal, structured visit coincident with the Annual Symposium; and a more informal visit in the Spring featuring detailed discussions with individual faculty and students. Board members have also visited the Center several times in addition to the regular board visits.

Interactions between the Center and the propulsion community also take the form of financial support for research in specific propulsion areas. Externally-funded research projects in conjunction with Lewis Research Center, Marshall Space Flight Center, and the Jet Propulsion Laboratory; Air Force, Army, and Navy laboratories; and Pratt and Whitney, General Electric, Aerojet, Rocketdyne, TRW, and Lockheed were underway during the present reporting period.

In service-oriented areas, Center faculty have been members of Technical Review groups for several NASA projects and have participated in numerous NASA and JANNAF panels, workshops, and consortia. Faculty and students from the Center have visited Lewis and Marshall many times during the year, and many NASA and Air Force employees visited the Center over the past year.

Table 6. Papers Presented at the Fifth Annual Symposium The Pennsylvania State University University Park, PA

I. Steady State Combustion and Performance

Measurement of Intact-Core Length of Atomizing Liquid Jets by Image Deconvolution - R. Woodward, R. Burch, F.-B. Cheung, and K. Kuo, PSU

Small Rocket Flowfield Diagnostic Chambers - B. Reed and S. Morren, Lewis Research Center

A Theoretical Evaluation of Aluminum Gel Propellant Two-Phase Flow Losses on Vehicle Performance - D. Mueller and S. Turns, PSU

Laser Diagnostics for Small Rockets - F. Zupanc and W. deGroot, Lewis Research Center

CFD Analyses of Combustor and Nozzle Flowfields - H.-H. Tsuei and C. Merkle, PSU

LOX Droplet Vaporization in a Supercritical Forced Convective Environment - C.C. Hsiao and V. Yang, PSU

Evaporation and Combustion of LOX Under Supercritical and Subcritical Conditions - A. Yang, K. Kuo, and W.-H. Hsieh, PSU

Droplet Turbulence Interactions Under Subcritical and Supercritical Conditions - E. Coy, S. Greenfield, M. Ondas, Y.-H. Song, T. Spegar, and D. Santavicca, PSU

SSME Fuel Preburner Injector Characterization - J. Hutt, Marshall Space Flight Center

Small Rocket Research and Technology - S. Schneider and J. Biaglow, Lewis Research Center

Fundamental Rocket Injector/Spray Programs at the Phillips Laboratory - D. Talley, Phillips Laboratory

An Experimental Study of Characteristic Combustion-Driven Flows for CFD Validation - S. Pal, M. Moser, J. Merenich, and R. Santoro, PSU

II. Heat Transfer and Fluid Mechanics

Numerical Investigation of Two- and Three-Dimensional Heat Transfer in Expander Cycle Engines - R. Burch and F.-B. Cheung, PSU

Flow Visualization Study in High Aspect Ratio Cooling Channels for Rocket Engines - M. Meyer and J. Giuliani, Lewis Research Center

CFD Analyses of Coolant Channel Flowfields - J. Yagley, J.-Z. Feng, and C. Merkle, PSU

Heat Transfer in Rocket Combustion Chambers - P. Anderson, G. Cheng, and R. Farmer, SECA, Inc.

Advanced Materials for Radiation-Cooled Rockets - B. Reed, J. Biaglow, and S. Schneider, Lewis Research Center

Molecular Gas Dynamics Applied to Low-Thrust Propulsion - D. Zelesnik and P. Penko, Lewis Research Center, and I. Boyd, Cornell University

CFD Applications in Rocket Propulsion Analysis and Design - P. McConnaughey, R. Garcia, L. Griffin, and J. Ruf, Marshall Space Flight Center

Efficiency and Reliability Enhancements in Propulsion Flowfield Modeling - P. Buelow, S. Venkateswaran, and C. Merkle, PSU

Computation of Propulsion-Related Flowfields Using Unstructured Adaptive Meshes - J. Weiss, FLUENT, Inc.

Dual-Bell Altitude Compensating Nozzles - S. Fisher and M. Horn, Rocketdyne

Table 6. Papers Presented at the Fifth Annual Symposium The Pennsylvania State University University Park, PA (Continued)

III. Combustion Stability

Numerical Parametric Studies of Spray Combustion Instabilities - M. Pindera, CFD Research
Spray Formation Processes of Impinging Jet Injectors - H. Ryan, W. Anderson, S. Pal, and R. Santoro, PSU
Inherent Stability of Central Element Coaxial Liquid-Liquid Injectors - F. Stoddard, TRW
Axisymmetric Single Shear Element Combustion Instability Experiment - K. Breisacher, Lewis Research Center
Development of a Droplet Breakup Model Considering Aerodynamic and Droplet Collision Effects - K. Wert and H.R. Jacobs, PSU
Development of a Computational Testbed for Numerical Simulation of Combustion Instability - J. Grenda, S. Venkateswaran, and C. Merkle, PSU
Shear Coaxial Injector Instability Mechanisms - T. Kaltz, M. Glogowski, and M. Micci, PSU

IV. Turbomachinery Aero- and Hydro-Dynamics

Foil Bearing Research at Penn State - M. Carpino, PSU
Two Stage Turbine for Rockets - J. Veres, Lewis Research Center
Computational Fluid Dynamic Modelling of Cavitation - M. Deshpande, J. Feng, and C. Merkle, PSU
A Technique to Measure Rotordynamic Coefficients in Hydrostatic Bearings - R. Capaldi, Lewis Research Center
Computation of Flows in a Turn-Around Duct and a Turbine Cascade Using Advanced Turbulence Models - B. Lakshminarayana and J. Luo, PSU
Brush Seals for Cryogenic Applications - M. Proctor, Lewis Research Center
Reliability Enhancement of Navier-Stokes Codes Through Convergence Enhancement- K.-Y. Choi and G. Dulikravich, PSU

V. Advanced Space Propulsion Concepts

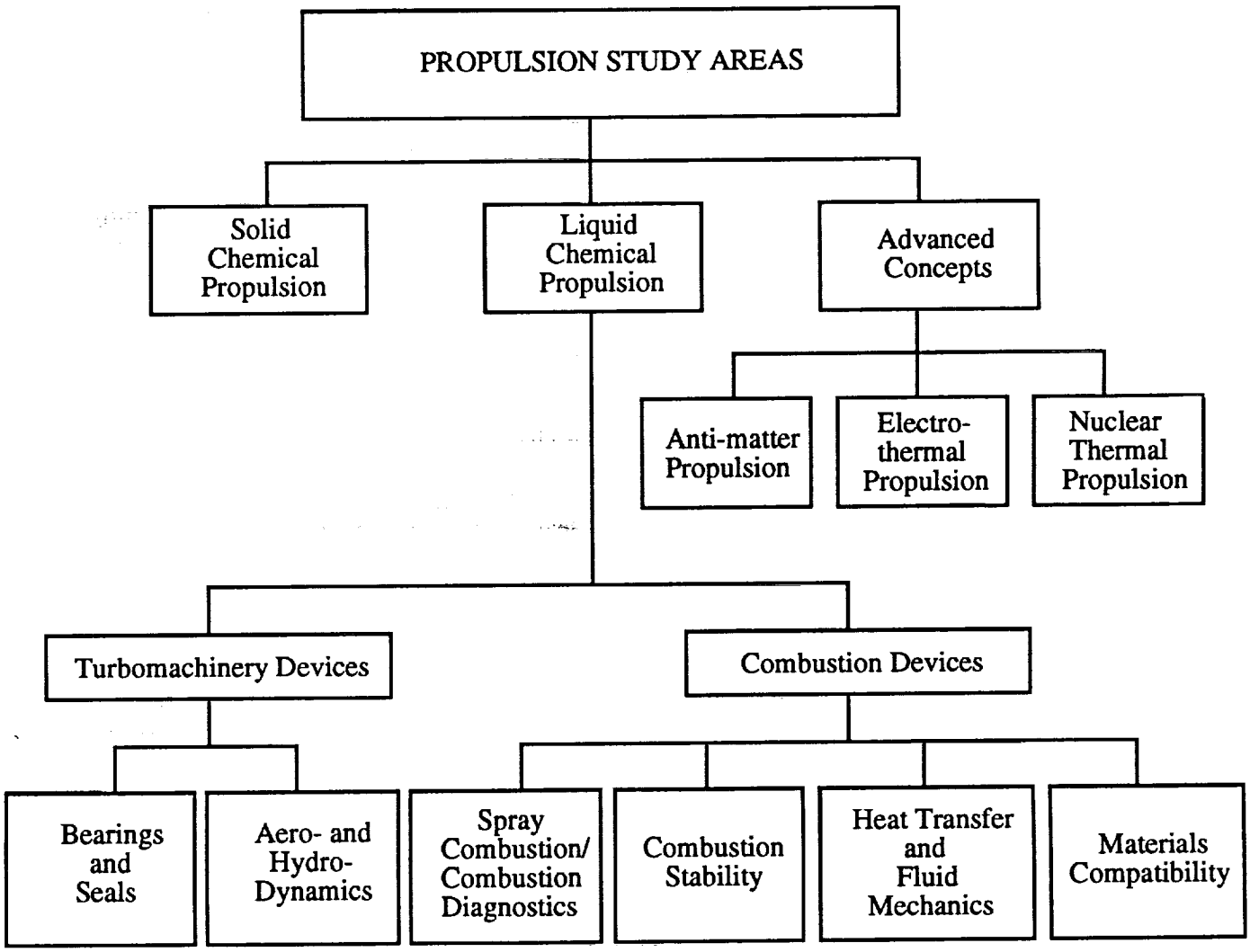
Optimization of Energy Transfer in Microwave Electrothermal Thrusters- D. Sullivan and M. Micci, PSU
CFD Modeling of Microwave Electrothermal Thrusters - D. Schwer, S. Venkateswaran, and C. Merkle, PSU
Advanced Space Propulsion Concepts - M. LaPointe, Lewis Research Center
Advanced Space Nuclear Thermal Propulsion Concepts - S. Howe, Los Alamos National Laboratory
An Anti-Proton Driver for ICF Propulsion - G. Smith, P.-R. Chiang, R. Lewis, C. Gazze, K. Higman, R. Newton, M. Chiaverini, J. Dailey, M. Surratt, W. Werthman, P. Cracraft, and S. Chakrobarti, PSU
Performance Assessment of Low Pressure Nuclear Thermal Propulsion - H. Gerrish and G. Doughty, Marshall Space Flight Center
Nuclear Propulsion Control and Health Monitoring - P. Walter and R. Edwards, PSU

V. RESEARCH

The Center research program consists of three main areas that cover most space transportation applications: liquid chemical propulsion, advanced propulsion concepts, and solid chemical propulsion. An outline of these three areas and the subcomponents they include is given in Fig. 4. This breadth across propulsion areas exposes Center students to a variety of significant propulsion technologies currently in use as well as those representing long-term applications. The long range plan of the Center is to continue to cover a broad array of propulsion technologies, including chemical, electric, and advanced propulsion concepts.

Liquid chemical propulsion, the dominant area of interest to the US space program today and in the foreseeable future, is the Center's research area of emphasis. The liquid chemical propulsion emphasis is segmented into two focal areas that contain the bulk of the research being performed at the Center: combustion devices and turbomachinery. This depth in the liquid rocket area promotes synergy between individual research projects and stimulates research excellence. A strong combustion research program in gas turbine, diesel, and spark ignition engines that complements the liquid rocket research also exists within the Center. Additional turbomachinery and materials research programs at the University also provide a major resource to Center personnel through course work and formal and informal interactions.

FIGURE 4. PROGRAM STUDY AREAS IN PROPULSION

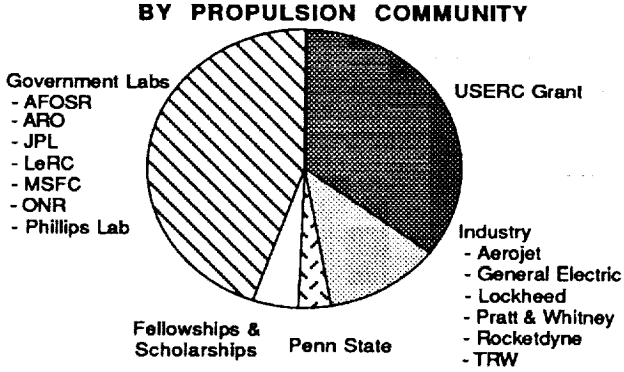


The US propulsion community recognizes that the students, faculty, and staff of the Propulsion Engineering Research Center represent a significant resource. This recognition is indicated in Fig. 5, which shows the present relative research support between industry, government laboratories, and the USERC grant, as well as support received from the university and through fellowships and scholarships. The USERC grant provides the base that has allowed the Center to become a resource for the US propulsion community.

The Center's strategy to establish itself as a world leader in propulsion research called for the development of an assembly of unique experimental and computational capabilities. Experimentalists at the Center have been at the forefront in the development and application of non-intrusive diagnostic techniques to study combustion and fluid mechanics. As a result, laser-based measurement systems are used extensively throughout the Center's program. Laboratories are well-equipped with state of the art test devices and measurement systems. Center laboratories include the Cryogenic Combustion Laboratory, the Metallized Propellant Laboratory, the Electric Propulsion Laboratory, the Magnetic Bearings Laboratory, the Hydrogen Permeation Laboratory, the Turbulent Combustion Laboratory, the Spray Combustion Laboratory, and the Computational Fluid Dynamics Laboratory.

The Cryogenic Combustion Laboratory is a key part of the Center's research effort in liquid chemical propulsion that was developed to enable fundamental experimental research on rocket engine combustion, materials compatibility, and heat transfer under realistic conditions. Detailed design and construction began shortly after Center start-up. The NASA Lewis Research Center, Air Products, Aerojet, and Rocketdyne were particularly helpful in providing advice, background knowledge, and practical considerations critical to bringing the Cryogenic Combustion Laboratory on line on schedule and within budget. At present, the laboratory is in routine research operation and is being used to produce benchmark data for CFD code validation and for studies on combustion instability mechanisms. Present capabilities include GOX/H_2, LOX/H_2, and GOX/CH_4 propellants, 1000 psia operating pressure and tests at the uni- and few-element scale.

FIGURE 5.
RESEARCH IS WIDELY SUPPORTED BY PROPULSION COMMUNITY



This unique laboratory was developed to address a critical need of experimental facilities and research expertise necessary to study rocket engine processes. A major emphasis in the Cryogenic Combustion Laboratory is the development and application of advanced diagnostic techniques for studying basic physical processes in hostile environments that can later be extended to actual rocket engine applications. The Cryogenic Combustion Laboratory also provides students with hands-on knowledge of the safety and practical issues associated with handling cryogenic propellants.

Extensive computational facilities include on-site microcomputers and workstations, the University mainframe computer, and ready access to supercomputers at a variety of locations across the country. The computing capability in the Propulsion Center is based on a local assembly of 20 RISC 6000 workstations, all connected through ETHERNET to the University fiber-optics network and external supercomputer centers. Center researchers are leading proponents of applying distributed work station resources to massively parallel CFD implementations.

An overview of the present Center research program is given below. First, a description of research programs in the liquid propulsion area is given, followed by a description of the efforts in advanced propulsion concepts. Abstracts of Center research projects in these study areas are contained in Volume II of this report, the Proceedings of the Fifth Annual Symposium. The well-established solid propellant propulsion research program, which predates the NASA Center and is an important source of synergism with our liquid propulsion work, is not discussed in detail here.

Liquid Chemical Propulsion

The largest research focus area in liquid chemical propulsion, combustion devices, is subdivided into four program areas: spray combustion and spray diagnostics, combustion stability, fluid mechanics and heat transfer, and materials compatibility. The turbomachinery research focus area is subdivided into two program areas: bearings and seals, and hydro- and aero-dynamics. In general, all these programs include a substantial experimental component with coordinated support in computational fluid dynamics (CFD) and/or other analytical areas.

Spray Combustion and Combustion Diagnostics

The combustion process in liquid rocket engines is controlled by the formation of propellant sprays and subsequent mixing and vaporization. Increased understanding of the spray combustion process and its management will lead to more durable and more economical rocket engines. The Center has developed a comprehensive research program in this area, focusing on the processes of primary and secondary atomization, droplet transport, and vaporization. The Center program emphasizes development of new experimental techniques to study spray and combustion processes, application of these techniques to gain further understanding into the basic processes, and development of theoretical models for propellant atomization and vaporization. This area is of critical importance to all liquid chemical propulsion applications and comprises the largest research effort within the combustion devices focal area, with 7 faculty, 25 graduate students, and 9 undergraduate students involved in the research effort.

Our experimental work in sprays includes complementary research on a broad subset of spray combustion issues that covers the important practical aspects. The common injector element types, impinging jet and shear and swirl coaxial jet injectors, are being studied to determine the incipient breakup mechanisms and to characterize the resultant spray field in terms of its droplet size and velocity distribution. These measurements are being compared to correlations currently in use by engine designers and to provide validation data for mechanistic atomization models in development at the Center. On the other side of the scale, individual droplets in isothermal, non-isothermal, and reacting conditions are also being studied to determine droplet drag, secondary atomization, ignition, and droplet heating characteristics. Experiments are also underway to provide data on evaporation and diffusion rates of LOX under a variety of conditions. Effects of sub- and super-critical thermodynamic operating conditions are also being evaluated in the above experiments.

An impressive number of innovative measurement techniques are being developed and applied at the Center to study combustion processes. Real-time X-ray radiography is being used to probe dense spray regions that are inaccessible to more traditional optical techniques. Planar and point optical techniques are being used to measure drop size and velocity distributions of dilute sprays and velocity-ignition histories of single droplets. Double-pulsed laser techniques are being used to measure droplet trajectories in turbulent flows to determine droplet drag. Exciplex thermometry is being used to measure droplet temperature and droplet vaporization rates. OH radical concentrations are being measured under simulated rocket engine conditions in a high-pressure laboratory combustor. The common interest in developing these experimental techniques introduces additional synergy into the research.

Analytical studies complement these experimental efforts. Development of mechanistic models of combustion processes is underway and model predictions are being compared to experimental data obtained at the Center and other research laboratories. Atomization models and models for two-phase non-isothermal phenomena in the near-critical and super-critical regimes are being developed. CFD models for reacting flows in combustor/nozzles are also being developed. An example of a cooperative research effort between a predominantly experimental group and a predominantly theoretical group that was enabled by the Center is a project to obtain benchmark quality data to provide to the entire liquid rocket propulsion community for validation of CFD-based combustion codes. A transparent rocket chamber was designed jointly by the two research groups with the requirement that the experiment produce data appropriate for code validation. To date, measurements of OH radical concentrations,

the size and velocity of LOX droplets, and gas velocity have been made in a combusting, high-pressure LOX/H_2 combustor and the results have been presented regularly at the CFD Consortium Meetings at NASA Marshall Space Flight Center.

Combustion Stability

The occurrence of high-frequency, high-pressure oscillations is a severe problem that has plagued rocket designers and one for which a mechanistic predictive design analysis capability is completely lacking. Combustion stability research at the Center emphasizes the understanding of the underlying initiation and sustenance mechanisms of combustion instability and the development of mechanistic models that can accurately predict the instability phenomena. There are currently five faculty, 11 graduate students, and four undergraduates working in this research area.

The Center has a comprehensive program in combustion instability. The two major injector types, coaxial jets (for LOX/H_2) and impinging jets (for LOX/HC and storable propellants) are being studied. The interactions between the unsteady flowfield and the primary combustion processes of atomization, spray formation, and droplet vaporization and burning are being studied both experimentally and theoretically. A CFD testbed is under development to evaluate combustion instability mechanisms numerically and for future use as a predictive design analysis tool. These combined results should help define the dominant coupling mechanism, and offer insight into appropriate strategies to deter initiation and growth of combustion instabilities.

Heat Transfer and Fluid Mechanics

Thrust chamber fluid mechanics and heat transfer impact performance, durability, and cost characteristics of liquid rocket engines. The Center's research program in this area emphasizes the development of analytical tools to study the problem, as well as experiments for model validation. Fluid mechanics research at the Center is focused on methods to optimize nozzle performance for small space thrusters, while heat transfer research emphasizes developing analysis tools to quantify design and operating condition effects on chamber wall heat transfer. This program area constitutes the research efforts of five faculty, nine graduate students, and one undergraduate student.

Heat transfer research includes work on expander cycle engines and high-aspect ratio cooling channels. Expander cycle engines afford potential benefits of benign and simple operation leading to longer component lifetime. The efficiency of expander cycle engines depends on heat transfer to the thrust chamber coolant, which also acts as the working fluid in the turbine drive unit. CFD-based analyses are underway to evaluate methods to enhance heat transfer from the hot gases inside the combustor to the coolant flowing through outside channels surrounding the chamber. High-aspect ratio cooling channels are used in many modern combustor wall designs to improve fabricability and heat transfer efficiency. Again, CFD models are being developed to account for geometry-driven secondary flowfields and their effects on heat transfer. These computational approaches may help identify practical means for extending combustor lifetime without performance decrements.

Small space thrusters operate at relatively low Reynolds number conditions and typically experience greater performance losses due to viscous boundary layers than do large engines. Here, Center research involves development of theoretical means to study low Reynolds number chamber and nozzle flows and to analyze the effect of operating and design conditions on engine performance. Classical instability methods are being used to determine the laminar-turbulent transition point in the diverging nozzle. Monte-Carlo simulations of very low Reynolds number nozzle flowfields are being performed to assess the performance of trumpet nozzles and other alternate nozzle types for space-based propulsion applications. Navier-Stokes CFD models are being developed for the analysis of combustor-nozzle flowfields of small space thrusters to evaluate the effects of fuel film cooling. These analyses will potentially provide information on design means to control viscous and mixing losses.

Bearings and Seals

The second major liquid propulsion research category - turbomachinery devices -

features programs in bearings and seals and aero- and hydro-dynamics. Bearings and seals are critical elements in turbomachinery component designs. The Center research program in this area is directed toward resolution of technical issues related to the development of advanced designs that offer the potential of enhanced dynamic performance and virtually infinite life in very high-speed applications. There were three faculty, five graduate students, and one undergraduate student working in this area during the present reporting period. The Center program includes development of analytical methods to study the fluid-structure interaction between flexible foil bearings and lubricants, and development of control algorithms to reduce electrical power requirements and rotor shaft vibrations of magnetic bearings.

Aero- and Hydro-Dynamics

Detailed understanding of the complex fluid mechanics of flows through centrifugal pumps and turbines is necessary for improving the robustness and decreasing the cost of these critical liquid rocket engine components. The Center's research program in aero- and hydro-dynamics is focused on the development and improvement of CFD-based models for turbomachinery component design analysis. Three faculty, nine graduate students, and one undergraduate student are presently working in this area.

The emphasis here is on developing improved computational models, including improved turbulence models for pump and turbine geometries, advanced models for pump and inducer cavitation, and methods for enhancing the convergence rates of traditional algorithms for representative problems in turbomachinery. This work is co-funded by NASA Marshall, industry and the Center.

Advanced Propulsion Concepts

Advanced propulsion concepts that offer significant performance benefits and mission enablement for both near- and far-term applications complement our efforts in liquid rocket propulsion. The Center's advanced propulsion program is oriented toward building the technical foundation required for the practical use of these concepts. The Center's program emphasizes electro-thermal, nuclear-thermal, and fusion-based propulsion systems. Four faculty, 12 graduate students, and 3 undergraduates are currently working in this general area at the Center.

A major area of focus here is the use of antiproton-induced fission fragments to ignite deuterium pellets for inertial confined fusion propulsion. This effort offers dramatic potential payoffs in terms of performance for future space missions. Center researchers are jointly studying the prospects of an electrothermal propulsion concept based upon microwave heating of a working fluid. This effort includes both experiments and corresponding CFD modeling. These research projects receive support from the Jet Propulsion Laboratory, the Air Force Office of Scientific Research, the Air Force Phillips Laboratory and the Center.

A research project on condition monitoring of nuclear propulsion systems was initiated during the previous reporting period. The Center will stay aware of national goals in the nuclear propulsion arena so it can contribute to critical research issues in this significant new area as the need arises. Common disciplinary areas between nuclear propulsion and liquid chemical propulsion will form the focus of potential efforts in this direction. Computational fluid dynamics, heat transfer, and materials compatibility represent a few such possibilities. The extent of the Center's expansion into nuclear propulsion will depend upon the nation's future space directions and national propulsion programs.

VI. SUMMARY

The Propulsion Engineering Research Center has been highly successful on all major fronts. We continue to have outstanding success in attracting quality graduate students. We have a successful minority program in place. Our research program is of high quality and is directly relevant to the US national space program. In addition, we continue to maintain strong interactions and technical interchange with the national propulsion community. The success of these endeavors is clearly attributable to the presence of the USERC Center.

The Center's presence has made it possible to attract some of the brightest young men and women in America to careers in propulsion. The number of well-qualified US students who choose to study at the Center has increased slightly over the previous year. Presently, 87 graduate students and 24 undergraduate students are participating in the research and educational activities of the Center. Thirty-one students from the Center have graduated and are working in the US space program. Seven of ten of our current graduate student population are US citizens. The major portion of our USERC funds go directly into student support, and we expect this pattern to continue during the coming year. We are actively involved in encouraging the next generation of students to consider mathematics and science options through our participation in K-12 outreach programs.

We have a successful undergraduate minority program in place that has been augmented by a similar College-wide program with support from the National Science Foundation. Although our primary impact has been at the undergraduate level, we have begun to see positive impacts on our graduate program as well.

We continue to maintain a balance between breadth and depth in the research program. Our primary depth area is in liquid propulsion, with focus areas in combustion devices and turbomachinery aero- and hydro-dynamics. The liquid propulsion research area is well established and has a broad perspective. The breadth of the Center is enhanced by our efforts in solid propellant and advanced propulsion areas, which continues to be an effective means of exposing students to a broad propulsion perspective.

The Cryogenic Combustion Laboratory, which features capability for LOX/H_2 combustion, is on line and in routine operation. This Laboratory represents a unique research facility that enables us to make effective contributions both in terms of research and student education. Acquisition of experimental data at realistic operating conditions and geometries, and development and application of advanced non-intrusive diagnostic techniques for the severe rocket combustor environment are emphasized at the Cryogenic Combustion Laboratory.

The Center has established strong ties with the space propulsion industry in many ways, including graduate placement, joint research projects, professional meetings, organized seminar series, and service on professional committees. We have particularly strong interaction with NASA's primary propulsion centers, LeRC and MSFC, the primary liquid propulsion contractors, and other propulsion-related government agencies.

These areas summarize the present state of the Propulsion Center. The quantity and quality of students attracted to space propulsion have been outstanding. The impact on minorities would have been impossible without the Center. Excellent experimental and computational facilities enhance the quality and relevance of our research results, with the Cryogenic Combustion Laboratory being of particular note. We have developed very strong interactions with the propulsion community through a variety of paths, and have attracted a substantial amount of external funds. We are providing a steady supply of students with advanced degrees who wish to start their professional careers in propulsion in the US. All of these areas of success are directly attributable to the presence of the Center established by the University Space Engineering Research Center program.

APPENDIX A.

CENTER RESEARCH PROGRAM STUDY AREAS

A.1 LIQUID PROPELLANT ROCKET ENGINES

A.1.1 Combustion and Combustion Devices

A.1.1.1 Spray Combustion and Combustion Diagnostics
A.1.1.2 Combustion Stability
A.1.1.3 Fluid Mechanics and Heat Transfer
A.1.1.4 Materials Compatibility

A.1.2 Turbomachinery

A.1.2.1 Bearings and Seals
A.1.2.2 Hydro- and Aero-Dynamics

A.2 ADVANCED PROPULSION CONCEPTS

A.3 SOLID PROPELLANT PROPULSION

APPENDIX A. CENTER RESEARCH PROGRAM STUDY AREAS

A.1 LIQUID PROPELLANT ROCKET ENGINES

A.1.1 Combustion and Combustion Devices

A.1.1.1 Spray Combustion and Combustion Diagnostics

Faculty Involved	Students Supported	Funding Agencies[1]
F.-B. Cheung	Michelle Beisler (MS)	Aerojet
W.-H. Hsieh	Edward Coy (PhD)	AFOSR
K.K. Kuo	Thomas DeMurry (BS)	AFPL Palace Knight
D.A. Santavicca	Michael Foust (PhD)	ARO
R.J. Santoro	Kevin Gibbons (BS)	MSFC
S.R. Turns	Aaron Golub (BS)	NSF
V. Yang	Stuart Greenfield (PhD)	ONR
	Sreenath Gupta (PhD)	PERC
	Jodi Hansen (BS)	Rocketdyne
	George Harting (MS)	
	Michael Hayner (BS)	
	C.C. Hsiao (PhD)	
	Mark Kirby (BS)	
	Simon Leonard (MS)	
	Douglas Leone (MS)	
	Norman Lin (PhD)	
	Robert Malony (BS)	
	John Merenich (MS)	
	Desmond Miller (BS)	
	Marlow Moser (PhD)	
	Donn Mueller (PhD)	
	David Nye (PhD)	
	Michael Ondas (PhD)	
	Kenneth Phillapart (PhD)	
	Thomas Prevish (PhD)	
	Shamim Rahman (PhD)	
	Thomas Richardson (PhD)	
	Matthew Schneider (BS)	
	Young-Hoon Song (PhD)	
	Timothy Spegar (PhD)	
	James Withington (PhD)	
	Roger Woodward (PhD)	
	Andrew Yang (PhD)	
	David Yoset (MS)	

A.1 LIQUID PROPELLANT ROCKET ENGINES

A.1.1 Combustion and Combustion Devices (Continued)

A.1.1.2 Combustion Stability

Faculty Involved	Students Supported	Funding Agencies[1]
H.R. Jacobs	William Anderson (PhD)	AFOSR
C.L. Merkle	John Carosi (BS)	MSFC
M.M. Micci	Ecton English (BS)	PERC
R.J. Santoro	Michael Glogowski (PhD)	TRW
V. Yang	Jeffrey Grenda (PhD)	
	David Grupp (BS)	
	John Hutt (PhD)	
	Theresa Kaltz (PhD)	
	Joseph Oefelein (PhD)	
	Harry Ryan (PhD)	
	Frank Tseng (PhD)	
	Jaime Vasquez, Jr. (BS)	
	Kevin Wert (PhD)	
	Josef Wicker (PhD)	
	Myong-Won Yoon (PhD)	

A.1.1.3 Fluid Mechanics and Heat Transfer

Faculty Involved	Students Supported	Funding Agencies[1]
F.-B. Cheung	Jeffrey Auston (PhD)	LeRC
C.L. Merkle	Robert Burch (PhD)	MSFC
M.M. Micci	Andrea Frohman (PhD)	NSF
L.L. Pauley	Roy Hilton (MS)	PERC
V. Yang	Long-Shin Lee (PhD)	Pratt - Whitney
	J. Y. Oh (PhD)	
	Tae-Seong Roh (PhD)	
	Jabbar Thomas (BS)	
	H. H. Tsuei (PhD)	
	Jennifer Yagley (PhD)	

A.1.1.4 Materials Compatibility

Faculty Involved	Students Supported	Funding Agencies[1]
R.N. Pangborn	Eric Roll (PhD)	PERC
R.A. Queeney		

A.1 LIQUID PROPELLANT ROCKET ENGINES

A.1.2 Turbomachinery

A.1.2.1 Bearings and Seals

Faculty Involved	Students Supported	Funding Agencies[1]
M. Carpino	Walter DeMoss (BS)	LeRC
A. Sinha	Eric Hornchek (MS)	PERC
K.-W. Wang	Keith Hurley (MS)	
	Scott Lewis (PhD)	
	Lynn Medvetz (MS)	
	Jih-Ping Peng (PhD)	

A.1.2.2 Hydro- and Aero-Dynamics

Faculty Involved	Students Supported	Funding Agencies[1]
G. Dulikravich	Philip Buelow (PhD)	LeRC
B. Lakshminarayana	Kwang Choi (PhD)	MSFC
C.L. Merkle	Manish Deshpande (PhD)	PERC
	Norman Foster (BS)	Pratt - Whitney
	Michael Korio (MS)	
	Jiang Liou (PhD)	
	Thomas Martin (PhD)	
	Paul Paradis (MS)	
	Scott Sheffer (MS)	
	Michael Zaccaria (PhD)	

A.2 ADVANCED PROPULSION CONCEPTS

Faculty Involved	Students Supported	Funding Agencies[1]
R.M. Edwards	Suman Chakrabarti (PhD)	AFOSR
C.L. Merkle	Martin Chiaverini (MS)	AFPL
M.M. Micci	Philip Cracraft (BS)	AFPL Palace Knight
G.A. Smith	Russell Daines (PhD)	JPL
	James Dailey (MS)	LeRC
	Christopher Gazze (PhD)	MSFC
	Kumiko Higman (PhD)	NSF
	Steven Nagle (BS)	PERC
	Richard Newton (PhD)	Pratt - Whitney
	Kevin Powell (BS)	Rocketdyne
	Douglas Schwer (PhD)	
	Daniel Sullivan (PhD)	
	Michael Surratt (PhD)	
	Philip Walter (PhD)	
	Lance Werthman (MS)	

A.3 SOLID PROPELLANT PROPULSION

Faculty Involved	Students Supported	Funding Agencies[1]
F.-B. Cheung	Paul Alaksin (BS)	Aerojet
K.K. Kuo	Jeffrey Brown (MS)	AFPL
T.A. Litzinger	W.-W. Chu (PhD)	ARO
V. Yang	Daniel Cohen (MS)	Lockheed
	Barry Fetherolf (PhD)	ONR
	Richard Field (PhD)	Thiokol
	Todd Freyman (MS)	
	T. H. Huang (PhD)	
	Robert Kokal (MS)	
	Benoy Kumar (PhD)	
	Julian Laxton (BS)	
	Y.C. Liau (PhD)	
	Peter Liiva (PhD)	
	Yeu-Cherng Lu (PhD)	
	Matthew Mench (BS)	
	Michael Paulaskas (BS)	
	Randy Salizzoni (PhD)	
	J. S. Tseng (PhD)	
	Eric Weaver (BS)	
	Seng-Rung Wu (PhD)	

[1] AFPL - Air Force Phillips Laboratory
ARO - Army Research Office
AFOSR - Air Force Office of Scientific Research
JPL - NASA Jet Propulsion Laboratory
LeRC - NASA Lewis Research Center
MSFC - NASA Marshall Space Flight Center
NSF - National Science Foundation
ONR - Office of Naval Research
PERC - NASA Propulsion Engineering Research Center
TRW - TRW, Inc.

APPENDIX B.

CENTER PERSONNEL

APPENDIX B. CENTER PERSONNEL

B.1 PARTICIPATING FACULTY AND STAFF MEMBERS

Faculty

Marc Carpino	Assistant Professor of Mechanical Engineering
Fan-Bill Cheung	Professor of Mechanical Engineering
George S. Dulikravich	Associate Professor of Aerospace Engineering
Robert M. Edwards	Assistant Professor of Nuclear Engineering
Wen Hsieh	Assistant Professor of Mechanical Engineering
Harold R. Jacobs	Professor and Head of Mechanical Engineering
Kenneth K. Kuo	Distinguished Professor of Mechanical Engineering
Budugur Lakshminarayana	Evan Pugh Professor of Aerospace Engineering
Thomas A. Litzinger	Associate Professor of Mechanical Engineering
Charles L. Merkle	Distinguished Alumni Professor of Mechanical Engineering/ Director of Propulsion Engineering Research Center
Michael M. Micci	Associate Professor of Aerospace Engineering
Robert N. Pangborn	Professor of Engineering Science and Mechanics
Laura L. Pauley	Assistant Professor of Mechanical Engineering
Richard A. Queeney	Professor of Engineering Science and Mechanics
Domenic A. Santavicca	Professor of Mechanical Engineering
Robert J. Santoro	Professor of Mechanical Engineering/Associate Director of Propulsion Engineering Research Center
Alok Sinha	Professor of Mechanical Engineering
Gerald A. Smith	Professor of Physics
Stephen R. Turns	Professor of Mechanical Engineering
Kon-Well Wang	Associate Professor of Mechanical Engineering
Vigor Yang	Associate Professor of Mechanical Engineering

Staff

Cheryl Adams	Staff Assistant
William Anderson	Assistant Director
Penny Barr	Staff Assistant
Daniel Boone	Research Assistant
Jinzhang Feng	Research Associate
LaRue Jacobs	Staff Assistant
Taewoo Lee	Research Associate
Sibtosh Pal	Research Associate
Rahul Puri	Research Associate
John Raiser	Administrative Coordinator
Larry Schaaf	Research Assistant
Virginia Smith	Staff Assistant
Richard Steinberger	Research Associate
Sankaran Venkateswaran	Research Associate

B.2. 1992-93 TRAINEES

Name	Major	Degree Sought	Advisor	Expected Graduation Date
Philip Buelow	ME	PhD	Merkle	May '95
Jeffrey Grenda	ME	PhD	Merkle	August '94
Doug Leone	ME	MS	Turns	May '93
Marlow Moser	ME	PhD	Santoro	May '94
Donn Mueller	ME	PhD	Turns	May '94
Michael Ondas	AERO	PhD	Santavicca	May '95
Kenneth Philippart	AERO	PhD	N/A	May '98
Thomas Prevish	ME	PhD	Santavicca	May '98
Harry Ryan	ME	PhD	Santoro	May '94
Douglas Schwer	AERO	PhD	Merkle	May '96
Kevin Wert	ME	PhD	Jacobs	May '94
Lance Werthman	AERO	MS	Smith	May '95
Joseph Wicker	AERO	PhD	Yang	May '95
David Yoset	ME	MS	Turns	May '93

B.3. RA'S SUPPORTED BY BASIC GRANT

Name	Major	Degree Sought	Advisor	Graduation Date
William Anderson	ME	PhD	Santoro	December '94
Michelle Beisler	ME	MS	Santoro	May '94
Martin Chiaverini	AERO	PhD	Smith	May '94
Manish Deshpande	ME	PhD	Merkle	August '94
Todd Freyman	ME	MS	Kuo	December '94
Michael Glogowski	AERO	PhD	Micci	May '94
Sreenath Gupta	ME	PhD	Santoro	May '96
Keith Hurley	ME	MS	Carpino	May '95
Robert Kokal	ME	MS	Kuo	December '93
Michael Korio	AERO	MS	Lakshminarayana	December '95
Thomas Martin	AERO	PhD	Dulikravich	December '96
Daniel Sullivan	AERO	PhD	Micci	May '94
Hsin-Hua Tsuei	ME	PhD	Merkle	December '94
Jennifer Yagley	ME	PhD	Merkle	May '95
Michael Zaccaria	AERO	PhD	Lakshminarayana	May '94

B.4. RA'S SUPPORTED BY EXTERNAL FUNDING OF CENTER PROJECTS

Name	Major	Degree Sought	Advisor	Graduation Date
Jeffrey Auston	AERO	PhD	Yang	May '96
Jeffrey Brown	ME	MS	Kuo/Thynell	May '94
Robert Burch	ME	PhD	Cheung/Kuo	May '94
Suman Chakrabarti	ME	PhD	Smith	May '95
Kwang Choi	AERO	PhD	Dulikravich	May '94
Wen-Wei Chu	ME	PhD	Yang	December '96
Daniel Cohen	ME	MS	Kuo	May '94
Edward Coy	ME	PhD	Santavicca	May '94
James Dailey	AERO	MS	Smith	May '94
Russel Daines	ME	PhD	Merkle	August '94
Michael Foust	ME	PhD	Santoro	May '96
Barry Fetherolf	ME	PhD	Kuo/Litzinger	December '93
Richard Field	ME	PhD	Kuo	December '93
Andrea Frohman	ME	PhD	Merkle	May '97
Christopher Gazze	NUC ENG	MS	Smith	August '93
Stuart Greenfield	ME	PhD	Santavicca	May '94
George Harting	AERO	MS	Kuo	August '94
Kumiko Higman	NUC ENG	PhD	Smith	August '93
Roy Hilton	ME	MS	Merkle	May '94
Eric Hornchek	ME	MS	Wang/Sinha	May '93
George Hsiao	ME	MS	Yang	August '94
Tzung-Huei Huang	ME	PhD	Kuo/Thynell	May '94
John Hutt	ME	PhD	Yang	December '95

B.4. RA'S SUPPORTED BY EXTERNAL FUNDING OF CENTER PROJECTS

Name	Major	Degree Sought	Advisor	Graduation Date
Teresa Kaltz	AERO	PhD	Micci	May '96
Benoy Kumar	ME	PhD	Kuo/Thynell	December '95
Long-Shin Lee	AERO	PhD	Pauley	May '95
Simon Leonard	ME	MS	Santoro	January '94
Scott Lewis	ME	PhD	Sinha/Wang	May '94
Y.-C. Liau	ME	PhD	Yang	May '97
Jiang Liou	AERO	PhD	Lakshminarayana	May '94
Norman Lin	ME	PhD	Yang	May '93
Peter Liiva	ME	MS	Litzinger	December '92
Yeu-Cherng Lu	ME	PhD	Kuo	December '92
Lynn Medvetz	ME	MS	Carpino	December '92
John Merenich	ME	MS	Santoro	December '93
Richard Newton	NUC ENG	PhD	Smith	May '95
David Nye	ME	PhD	Santavicca	January '94
Joseph Oefelein	ME	PhD	Yang	May '95
Jong Oh	ME	PhD	Yang	December '93
Paul Paradis	AERO	MS	Dulikravich	May '95
Jih-Ping Peng	ME	PhD	Carpino	May '93
Shamim Rahman	ME	PhD	Santoro	May '95
Thomas Richardson	ME	PhD	Santoro	June '93
Tae-Seong Roh	ME	PhD	Yang	May '94
Eric Roll	E. SCI.	PhD	Pangborn	May '93

B.4. RA'S SUPPORTED BY EXTERNAL FUNDING OF CENTER PROJECTS (Continued)

Name	Major	Degree Sought	Advisor	Graduation Date
Randy Salizzoni	ME	PhD	Kuo	August '95
Scott Sheffer	AERO	MS	Dulikravich	May '93
Young Hoon Song	ME	PhD	Santavicca	May '94
Timothy Spegar	ME	PhD	Santavicca	January '95
Michael Surratt	AERO	MS	Smith	
Frank Tseng	FUEL SCIENCE	PhD	Yang	August '93
I-Shieh Tseng	ME	PhD	Yang	December '92
Philip Walter	NUC ENG	PhD	Edwards	December '94
James Withington	AERO	PhD	Yang	December '92
Roger Woodward	ME	PhD	Kuo	August '93
Seng-Rung Wu	ME	PhD	Kuo	December '92
Andrew Yang	ME	PhD	Kuo	August '93
Myong Yoon	ME	PhD	Yang	May '93

B.5. UNDERGRADUATES, 1992-1993

Name	Major	Advisor
Paul Alaksin	ME/PSU	Kuo
John Carosi	ME/PSU	Santoro
Philip Cracraft	E.SCI/PSU	Smith
Walter DeMoss	ME/PSU	Carpino
Thomas DeMurry	ME/PSU	Santavicca
Ecton English	ME/Maryland	Santoro
Norman Foster	AERO/PSU	Dulikravich
Kevin Gibbons	ME/PSU	Santavicca
Aaron Golub	ME/VPI	Santavicca
David Grupp	ME/PSU	Santoro
Jodi Hansen	ME/PSU	Santavicca
Michael Hayner	ME/PSU	Santavicca
Mark Kirby	ME/PSU	Santavicca
Julian Laxton	ME/PSU	Kuo
Robert Malony	ME/PSU	Kuo
Matt Mench	ME/PSU	Kuo
Desmond Miller	AERO/PSU	Yang
Steven Nagle	AERO/E.SCI/PSU	Smith
Mike Paulaskas	ME/PSU	Kuo
Kevin Powell	AERO/PSU	Smith
Matthew Schneider	ME/Univ. of Iowa	Santoro
Jabbar Thomas	ME/Morehouse	Merkle
Jaime Vazquez, Jr.	Physics/Lincoln	Micci
Eric Weaver	ME/PSU	Kuo

B.6. GRADUATE PLACEMENT

Name	Degree	Current Employment
Mahesh Athavale	PhD, 1989	CFD Research
Philip Balaam	PhD, 1991	Matra Espace
Kristina Cairns	MS, 1990	Garrett
Gelsomina Cappuccio	MS, 1990	NASA Ames Research Center
J. L. Chen	PhD, 1991	Ford Motor Company
Yun Ho Choi	PhD, 1989	The Ajou University, Korea
Anthony Colozza	MS, 1989	NASA Lewis Research Center
Laura DeSimone	MS, 1990	Naval Surface Warfare Center
Barry Fetherolf	PhD, 1993	Martin Marietta
Mark Fisher	MS, 1990	NASA Marshall Space Flight Center
Y. T. Fung	PhD, 1991	General Physics
Kenneth Garner	MS, 1990	Westinghouse Electric
Christopher Gazze	MS, 1993	USAF
William Greene	MS, 1990	Martin-Marietta (NASA Marshall Space Flight Center)
David Hoover		Boeing
Eric Hornchek	MS, 1993	XiLinx
Ashvin Hosangadi	PhD, 1990	SAIC
Taras Jarymowycz	PhD, 1991	Lockheed
Randall Kanzleiter	MS, 1991	Research Assistant, Renssalaer Polytechnic Institute
Michael Kline	MS, 1992	Orbital Sciences
Simon Leonard	MS, 1994	Rolls-Royce, Canada
Douglas Leone	MS, 1993	Southwest Research Institute
Peter Liiva	MS, 1992	Texaco Fuels and Lubricants Laboratory
Norman Lin	PhD, 1993	Chung Shan Institute of Science & Technology
Yeu-Cherng Lu	PhD, 1992	Research Associate, Propulsion Engineering Research Center
Kevin Mease	MS, 1991	General Electric

B.6. GRADUATE PLACEMENT (Continued)

Name	Degree	Current Employment
Lynn Medvetz	MS, 1992	SKF
Jennifer Miller	PhD, 1993	NASA Langley Research Center
Ellsworth Minor	PhD, 1989	Post-doctoral Scholar, Laboratory for Elementary Particle Science, PSU
Juergen Mueller	PhD, 1991	Jet Propulsion Laboratory
Gary North	PhD, 1992	NASA Lewis Research Center
David Nye	PhD, 1994	Allison Gas Turbines
Kirsten Pace	MS, 1991	Aerospace Corporation
Sibtosh Pal	PhD, 1990	Research Associate, Propulsion Engineering Research Center
Kwang-Seo Park	MS, 1990	Hyundai
Jih-Ping Peng	PhD, 1993	Seagate Technology
Rahul Puri	PhD, 1992	Allison Gas Turbine
Thomas Richardson	Phd, 1993	Allison Gas Turbine
Eric Roll	PhD, 1993	PSU Faculty, Behrend Campus
Scott Sheffer	MS, 1993	Research Assistant, Princeton University
Charles Simchick	MS, 1990	Frick Company
Timothy Snyder	MS, 1990	UTRC
Robert Sonntag	MS, 1991	Pratt-Whitney
Michael Surrat	PhD, 1994	Air Force Phillips Laboratory
Jesse Tseng	PhD, 1992	Institute for Information Industry, Taiwan
Ronald Ungewitter	MS, 1989	Rocketdyne
Sankaran Venkateswaran	PhD, 1990	Research Associate, Propulsion Engineering Research Center
Brian Videto	PhD, 1992	Carrier Corporation
Jonathan Weiss	PhD, 1992	Fluènt
James Withington	PhD, 1992	Boeing
Roger Woodward	PhD, 1993	Air Force Phillips Laboratory

B.6. GRADUATE PLACEMENT (Continued)

Name	Degree	Current Employment
S.-R. Wu	PhD, 1992	Research Associate, Propulsion Engineering Research Center
Andrew Yang	PhD, 1993	Earth Satellite Propulsion Division, Taiwan
David Yoset	MS, 1993	Stone & Webster Engineering
Donna Zelesnik	MS, 1992	NASA Lewis Research Center

B.7. SUMMER UNDERGRADUATE PROGRAM PARTICIPANTS - 1989 through 1993

Name	Current Activity
Bernard Chatman	Sikorsky Aircraft
Gregory Davis	PSU Undergraduate- Electrical Engineering
Tabbetha Dobbins	Univ. of Pennsylvania Graduate School- Physics
Ecton English	Univ. of Maryland Undergraduate- Mechanical Engineering
Reginald Harrison	Prairie View A&M Undergraduate- Mechanical Engineering
Kendall Hayman	Versatron Corporation
Hernon Henderson	BSME Penn State Univ.
Alex Hollins	Lincoln University Undergraduate- Physics
Christopher Jervay	City College of Phila. Undergraduate- Engineering Science
Brian Mackey	Univ. of Southern Illinois Graduate School- Chemistry
Omaira Melendez	Duke University Graduate School- Chemistry
Desmond Miller	PSU Berks Campus Undergraduate- Aerospace Engineering
Kenneth Moore	MIT Graduate School- Biochemistry
Gayle Ramdeen	PSU Graduate School- Mechanical Engineering
William Reed	PSU Ogontz Campus- Undergraduate
Ted Reutzel	Georgia Inst. of Technology- Graduate School
Julie Richards	BSESci Penn State University
Yvette Scott	Lehigh University Graduate School- Physics
Scott Sheffer	Princeton University Graduate School
John Stallworth	Lincoln University Undergraduate- Chemistry
Chick Tanner	Mobil Oil Corporation
Jabbar Thomas	Morehouse College Undergraduate- Physics
Jaime Vasquez, Jr.	Lincoln University Undergraduate- Physics

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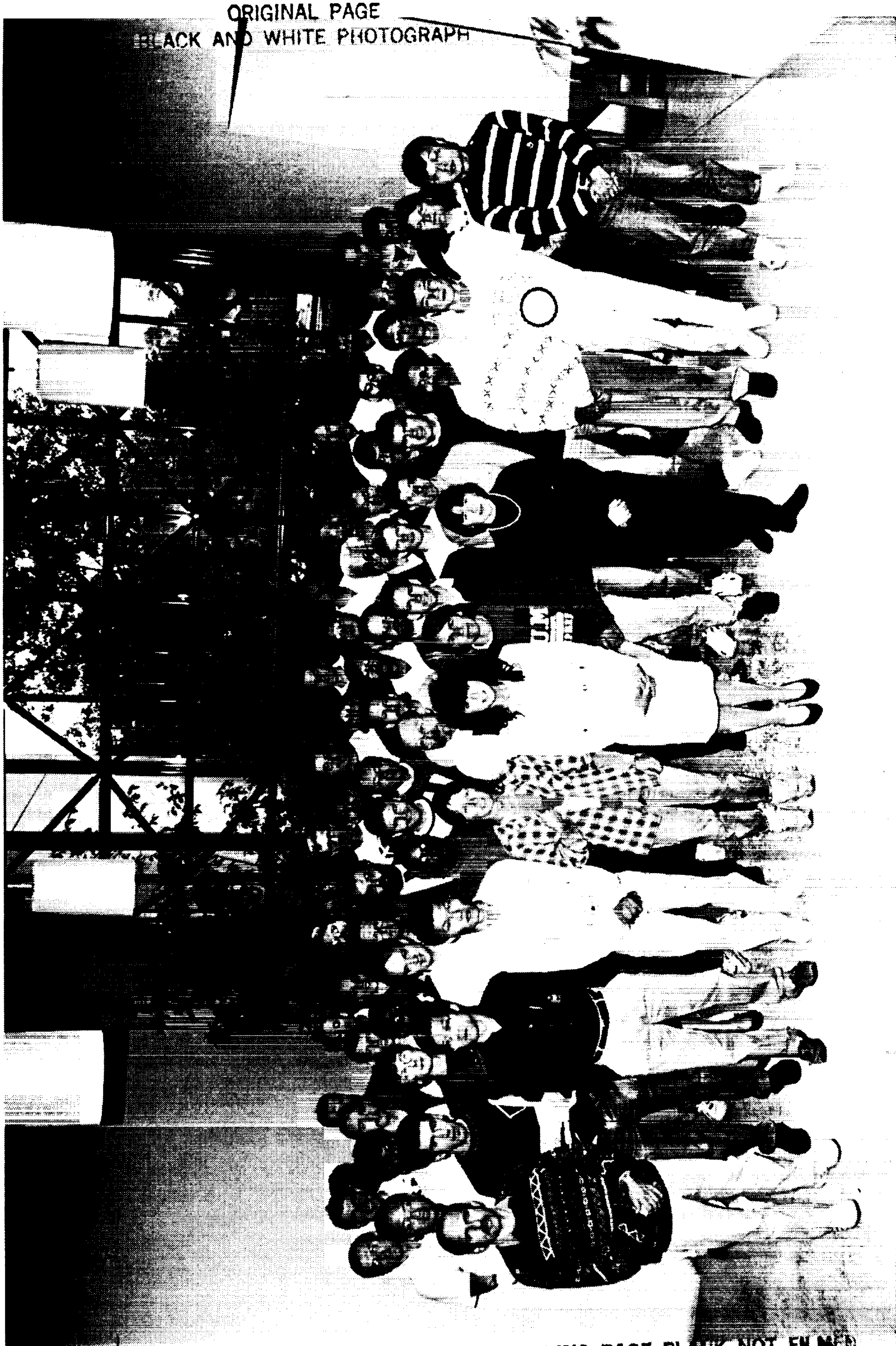

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APPENDIX C.

PUBLICATIONS, PRESENTATIONS, AND STUDENT AND FACULTY SPECIAL MENTIONS

C.1 JOURNAL AND OTHER REVIEWED PUBLICATIONS

C.2 CONFERENCE PROCEEDINGS AND PRESENTATIONS

C.3 AWARDS, SPECIAL MENTIONS, AND PANEL MEMBERSHIPS

APPENDIX C. PUBLICATIONS, PRESENTATIONS, AND STUDENT AND FACULTY SPECIAL MENTIONS

C.1 JOURNAL AND OTHER REVIEWED PUBLICATIONS

Armstrong, T.A., R. Bishop, V. Harris, R.A. Lewis, E. Minor, and G.A. Smith, "Energy Transfer by Intranuclear Cascade of Pi-Zeros Produced in Antiproton Annihilation at Rest in Nuclear Targets," Z. Phys., A332, 467 (1989).

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Chen, D.M., W.H. Hsieh, T.S. Snyder, V. Yang, T.A. Litzinger, and K.K. Kuo, "Combustion Behavior and Thermophysical Properties of Metal Based Solid Fuels," AIAA Journal of Propulsion and Power, Vol. 7, No. 2, pp. 250-257 (1991).

Chen, J.L., F.B. Cheung, and K.K. Kuo, "Effects of Electrical/Chemical Energy Input on the Interior Ballistics of an Electrothermal Chemical Gun," Propellants, Explosives, Pyrotechnics, Vol. 17, pp. 131-138 (1992).

Chen, J.L., K.K. Kuo, and F.B. Cheung, "Theoretical Model of the Interior Ballistics Processes in an Electrothermal Gun," Journal of Propulsion and Power, Vol. 8, No. 3, pp. 655-666 (1992).

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Chen, J.L., F.B. Cheung, and K.K. Kuo, "Theoretical Modeling of the Interior Ballistic Processes in an Electrothermal Chemical Gun," Journal of Propulsion and Power, Vol. 8, No. 3, pp. 655-666 (1992).

Chen, S., and A. Sinha, "Probabilistic Method to Compute the Optimal Slip Load for a Mistuned Bladed Disk Assembly with Friction Dampers," ASME Journal of Vibration and Acoustics, Vol. 112, April, pp. 214-221 (1990).

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Dulikravich, G.S. and T.J. Martin, "Inverse Design of Three-Dimensional Shapes With Overspecified Thermal Boundary Conditions," Monograph on Inverse Problems in Mechanics, Editor: S. Kubo, Tokyo, Japan, 1993.

Dulikravich, G.S. and T.J. Martin, "Determination of Void Shapes, Sizes and Locations Inside an Object with Known Surface Temperature and Heat Flux," IUTAM Symposium on Inverse Problems in Engineering Mechanics, Tokyo, Japan, May 11-16, 1993, Ed: M. Tanaka and H.D. Bui, Springer-Verlag, pp. 489-496.

Fan, S. and B. Lakshminarayana, "A Modified Low Reynolds Number k-ε Model for Unsteady Turbulent Boundary Layer Flows," AIAA No. 93-0204, Aerospace Sciences Meeting, Reno, NV, January 1993, submitted for publication in AIAA Journal.

Feng, J. and C.L. Merkle, "An Interaction Noise Between Vortex and Airfoil, AIAA Paper No. 93-0600, AIAA Paper No. 93-0235, 31st Aerospace Sciences Meeting & Exhibit, Reno, NV, January 11-14, 1993.

Gallardo, J.F. and B. Lakshminarayana, "Computation of Curved Flows Using Modified Turbulence Models," AIAA Paper No. 93-0202, Aerospace Sciences Meeting, Reno, NV, January, 1993.

Grenda, J., S. Venkateswaran, and C. Merkle, "CFD Computations and Analyses," Propulsion Engineering Research Center Fifth Annual Symposium, The Pennsylvania State University, University Park, PA, September 8-9, 1993.

Grenda, J., S. Venkateswaran, and C.L. Merkle, "Three-Dimensional Analysis of Combustion Instabilities in Liquid Rocket Motors," AIAA Paper No. 93-0235, 31st Aerospace Sciences Meeting & Exhibit, Reno, NV, January 11-14, 1993.

Ho, Y.H. and B. Lakshminarayana, "Computation of Unsteady Viscous Flow Through Turbomachinery Blade Row Due to Upstream Rotor Wakes," ASME Paper No. 93-GT-321, ASME Meeting, Cincinnati, OH, May 24-27, 1993, to be published in J. Turbomachinery.

Hsiao, C.C. and V. Yang, "Supercritical Droplet Vaporization and Combustion," Propulsion Engineering Research Center Fifth Annual Symposium, The Pennsylvania State University, University Park, PA, September 8-9, 1993.

Kaltz, T., M. Milicic, M. Glogowski, and M.M. Micci, "Shear Coaxial Injector Spray Characterization," AIAA Paper No. 93-2190, AIAA/SAE/ASME/ASEE 29th Joint Propulsion Conference and Exhibit, June 28-30, 1993, Monterey, CA.

Kim, Y.S., and K.W. Wang, "A Pseudo-Sensor-Output-Feedback Approach for Semi-Active Structural Control," Proc. ASME Winter Annual Meeting, DSC-38, November 1992.

Kuo, K.K., R.A. Kokal, M. Paulauskas, P. Alaksin, and L.S. Lee, "Flame-Spreading Phenomena in e Fin-Slot Region of a Solid Rocket Motor," presented at the 29th AIAA/SAE/ ASME/ASEE Joint Propulsion Conference and Exhibit, Monterey, CA, AIAA Paper No. 93-2310, June 28-30, 1993.

Kuo, K.K., T.A. Litzinger, and W.H. Hsieh, "Interrelationship Between Solid-Propellant Combustion and Material's Behavior," Presented at the MRS Meeting, Boston, MA., November 30 - December 4, 1992. Published in the Symposium Proceedings on Structure and Properties of Energetic Materials, Vol. 296, pp. 331-348, 1993.

Lakshminarayana, B., "Computation of Turbomachinery Flows, Including Tip Clearance Effects," Pratt & Whitney, Toronto, Canada, November 10, 1992.

Lakshminarayana, B., "A Simplified Reynolds Stress Model for Unsteady Turbulent Boundary Layers," AIAA 31st Aerospace Sciences Meeting & Exhibit, January 1993.

Lakshminarayana, B., "Torque Converter Flow Field," University of Virginia, February 26, 1993.

Lakshminarayana, B., "Computation of Unsteady Flow Field Over an Airfoil," MIT-FFX Airfoil Meeting, David Taylor Research Center (ONR), March 20-30, 1993.

Lakshminarayana, B. and J. Luo, "Numerical Computation of Aerodynamics and Heat Transfer in a Turbine Cascade and Turn-Around Duct Using Advanced Turbulence Models," Proc. of CFD Workshop, NASA Huntsville, AL, April 18-23, 1993.

Lakshminarayana, B., Y.H. Ho, and A. Basson, "Numerical Simulation of Steady and Unsteady Viscous Flow in Turbomachinery Using Pressure Based Algorithm," Proc. of CFD Workshop, NASA Huntsville, AL, April 18-23, 1993.

Lakshminarayana, B., "Computational Techniques for Turbomachinery," Proc. Colloquium on Turbomachinery, Seoul, Korea, June 27-July 2, 1993.

Lakshminarayana, B., "Turbulence Modeling and Computation of Flow in Turn-Around Ducts and Turbine Blade Rows," Propulsion Engineering Research Center Fifth Annual Symposium, The Pennsylvania State University, University Park, PA, September 8-9, 1993.

Lakshminarayana, B., R. Kunz, and R. By, "Navier-Stokes Analysis of the Pump Flow Field of an Automotive Torque Converter," Proc. 1993 ASME Pump Symposium, submitted to J. Fluids Engineering.

Lee, J.G., T.-W. Lee, D.A. Nye, and D.A. Santavicca, "Interaction of Premixed Flames with Turbulent Kármán Vortex Streets," Eastern Section: The Combustion Institute-Fall Technical Meeting, 1993.

Lee, W., T.F. Richardson, and R.J. Santoro, "The Effects of Operating Pressure on Soot Formation in Laminar Diffusion Flames," presented at Combustion Fundamentals and Applications, Joint Meeting of the Central and Eastern States Sections of The Combustion Institute, March 15-17, 1993, New Orleans, LA.

Lee, Y.-T., J. Feng, and C.L. Merkle, "Time-Dependent Potential Flow Analysis of Rotor-Stator Systems," 6th International Conference on Numerical Ship Hydrodynamics, August 2-5, 1993, Iowa City, IA.

Lee, Y.-T., J. Feng, and C.L. Merkle, "Prediction of Vortex and Linear Cascade Interaction Noise," ASME Paper 93-GT-314, International Gas Turbine and Aeroengine Congress and Exposition, May 24-27, 1993, Cincinnati, OH.

Leonard, S., R. Puri, and R.J. Santoro, "Generation of CO and Smoke During Underventilated Combustion," presented at the 1993 Eastern States Section Meeting of The Combustion Institute, Princeton, NJ, October 25-28, 1993.

Lu, Y.C., K.K. Kuo, and S.R. Wu, "Crack Propagation Process in a Burning AP-Based Composite Solid Propellant," presented at the 29th AIAA/SAE/ASME/ASEE Joint Propulsion Conference and Exhibit, Monterey, CA, AIAA Paper No. 93-2168, June 28-30, 1993.

Luo, J. and B. Lakshminarayana, "Navier-Stokes Analysis of Turbine Flow Field and Heat Transfer," Proc. of 11th Intl. Symposium on Air-Breathing Engines, Tokyo, Japan, September 19-24, 1993.

Martin, T.J. and G.S. Dulikravich, "Reliability Enhancement of Navier-Stokes Codes Through Convergence Enhancement," Propulsion Engineering Research Center Fifth Annual Symposium, The Pennsylvania State University, University Park, PA, September 8-9, 1993.

Martin, T.J. and G.S. Dulikravich, "Direct Solution Method for Inverse Problems in Heat Conduction," 5th Annual Thermal and Fluids Analysis Workshop, NASA Lewis, Cleveland, OH, August 16-20, 1993.

Martin, T.J. and G.S. Dulikravich, "Unsteady Three-Dimensional Thermal Field Prediction in Turbine Blades Using Nonlinear BEM," 5th Annual Thermal and Fluids Analysis Workshop, NASA Lewis, Cleveland, OH, August 16-20, 1993.

Menon, S. and V. Yang, "Some Issues Concerning Active Control of Combustion Instability in a Ramjet," AIAA Paper No. 93-0116, AIAA 31st Aerospace Sciences Meeting, Reno, NV, January 1993.

Merenich, J., S. Pal, M.D. Moser, and R.J. Santoro, "Velocity Field Measurements in a Gaseous Hydrogen/Oxygen Rocket," presented at the 1993 Eastern States Section Meeting of The Combustion Institute, Princeton, NJ, October 25-28, 1993.

Merkle, C.L., "Application of Computational Fluid Dynamic Techniques to Engine Instability Studies," First International Symposium on Liquid Rocket Combustion Instability, The Pennsylvania State University, University Park, PA, January 18-20, 1993.

Merkle, C.L. and S. Venkateswaran, "Reacting Flow Computations at Subsonic Speeds," 5th International Symposium on Computational Fluid Dynamics, August 31-September 3, 1993, Sendai, Japan.

Merkle, C.L., J. Weiss, and S. Venkateswaran, "Efficient Implementation of Turbulence Modeling in Computational Schemes," Second U.S. National Congress on Computational Mechanics, August 16-18, 1993, Washington, D.C.

Micci, M.M., "PDPA Measurements of the Spray Produced by a Coaxial Injector," Presented at European Society of Propulsion, Vernon, France, May 17, 1993.

Milicic, M., M. Glogowski, and M. Micci, "Shear Coaxial Injector Instability Mechanisms," Propulsion Engineering Research Center Fifth Annual Symposium, The Pennsylvania State University, University Park, PA, September 8-9, 1993.

Moser, M., J. Merenich, S. Pal, and R. Santoro, "An Experimental Study of Characteristic Combustion-Driven Flows for CFD Validation," Propulsion Engineering Research Center Fifth Annual Symposium, The Pennsylvania State University, University Park, PA, September 8-9, 1993.

Mueller, D. and S.R. Turns, "Aluminized Propellants for Liquid Rockets: Effects of Secondary Atomization on Performance," Propulsion Engineering Research Center Fifth Annual Symposium, The Pennsylvania State University, University Park, PA, September 8-9, 1993.

Pal, S., M.D. Moser, H.M. Ryan, M.J. Foust, and R.J. Santoro, "Drop Size Measurements in a LOX/GH_2 Propellant Rocket," presented at Combustion Fundamentals and Applications, Joint Meeting of the Central and Eastern States Sections of The Combustion Institute, March 15-17, 1993, New Orleans, LA.

Pinson, J.A., T.A. Litzinger, and R.J. Santoro, "New Techniques for Quantitative Planar Soot Measurements," presented at the 1993 Eastern States Section Meeting of the Combustion Institute, Princeton, NJ, October 25-28, 1993.

Quay, B., T.W. Lee, and R.J. Santoro, "Spatially-Resolved Measurements of Soot Volume Fraction Using Laser-Induced Incandescence," presented at the 1993 Eastern States Section of The Combustion Institute, Princeton, NJ, October 25-28, 1993.

Rapp, D.C. and R.J. Santoro, "Measurements of Soot Growth Species Concentration in Diffusion Flames," presented at the 1993 Eastern States Section of The Combustion Institute, Princeton, NJ, October 25-28, 1993.

Richardson, T. and R.J. Santoro, "Soot Formation in Coannular Diffusion Flames: The Effect of Fuel Dilution with Inert Species," presented at the AIChE 1992 Annual Meeting, November 1-6, 1992, Miami, FL.

Ryan, H., W. Anderson, S. Pal, and R. Santoro, "Atomization Characteristics of Impinging Liquid Jets," presented at the 31st Aerospace Sciences Meeting and Exhibit, January 11-14, 1993, Reno, NV.

Ryan, H., W. Anderson, S. Pal, and R. Santoro, "Combustion Instability Phenomena of Importance to Liquid Propellant Engines," Propulsion Engineering Research Center Fifth Annual Symposium, The Pennsylvania State University, University Park, PA, September 8-9, 1993.

Santavicca, D.A., R.L. Steinberger, K.A. Gibbons, J.V. Citeno, and S. Mills, "The Effect of Incomplete Fuel-Air Mixing on the Lean Limit and Emissions Characteristics of a Lean Prevaporized Premixed (LPP) Combustor," AGARD 81st PEP Symposium, Colleferro, Italy, 1993.

Santoro, R.J., "Soot Particle Formation and Growth in Laminar Diffusion Flames," invited presentation at the Colloquium on Combustion, Princeton, NJ, October 28, 1993.

Santoro, R.J., "Chemical Mechanistic Approaches for the Suppression of Soot Formation in the Combustion of High Energy Density Fuels," Proceedings of the Sixth ONR Propulsion Meeting, Boulder, CO, August 31-September 2, 1993.

Santoro, R.J., "Mechanistic Effects of Soot Particles on CO Formation and Destruction in Diffusion Flames," presented at the Second Workshop on Developing a Predictive Capability for CO Formation in Fires, March 13-14, 1993, New Orleans, LA.

Santoro, R.J. and W.E. Anderson, "Primary Atomization Mechanisms of Impinging Jet Injectors," First International Symposium on Liquid Rocket Engine Combustion Instability, The Pennsylvania State University, University Park, PA, January 18-20, 1993.

Schwer, D., S. Venkateswaran, and C. Merkle, "CFD Modeling of Microwave Electrothermal Thrusters," Propulsion Engineering Research Center Fifth Annual Symposium, The Pennsylvania State University, University Park, PA, September 8-9, 1993.

Schwer, D., S. Venkateswaran, and C.L. Merkle, "Analysis of Microwave-Heated Rocket Engines for Space Propulsion," Paper No. AIAA-93-2105, 29th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, June 28-30, 1993, Monterey, CA.

Sheffer, S.G. and G.S. Dulikravich, "Constrained Optimization of Three Dimensional Hypersonic Vehicle Configurations," AIAA Paper 93-0039, Reno, NV, January 11-14, 1993.

Smith, G.A., Invited Paper, Workshop on Traps for Antimatter and Radioactive Nuclei, TRIUMF, Vancouver, British Columbia, February 25-27, 1993.

Smith, G.A., Seminar, Department of Chemical and Nuclear Engineering, U. New Mexico, March 30, 1993.

Smith, G.A., Presentation, Advanced Weapons Technology Symposium, Phillips Laboratory, Kirtland AFB, April 6-7, 1993.

Smith, G.A., P.-R. Chiang, R. Lewis, C. Gazze, K. Higman, "An Anti-Proton Driver for ICF Propulsion," Propulsion Engineering Research Center Fifth Annual Symposium, The Pennsylvania State University, University Park, PA, September 8-9, 1993.

Song, Y.H. and D.A. Santavicca, "An Experimental Study of Drag and Lift Forces Acting on an Evaporating Droplet Along a Curvilinear Trajectory," Eastern Section: The Combustion Institute-Fall Technical Meeting, 1993.

Song, Y.H. and D.A. Santavicca, "An Experimental Study of Droplet Motion in a Highly Turbulent Flow," Eastern Section: The Combustion Institute-Fall Technical Meeting, 1993.

Sullivan, D. and M. Micci, "Optimization of Energy Transfer in Microwave Electrothermal Thrusters," Propulsion Engineering Research Center Fifth Annual Symposium, The Pennsylvania State University, University Park, PA, September 8-9, 1993.

Sullivan, D.J. and M.M. Micci, "Development of a Microwave Resonant Cavity Electrothermal Thruster Prototype," 23rd International Electric Propulsion Conference, Seattle, WA, September 13-16, 1993.

Tsuei, H.-H., S. Venkateswaran, and C. Merkle, "CFD Analyses of Combustor and Nozzle Flowfields," Propulsion Engineering Research Center Fifth Annual Symposium, The Pennsylvania State University, University Park, PA, September 8-9, 1993.

Turns, S.R. and R.V. Bandaru, "Carbon Monoxide Emissions from Turbulent Nonpremixed Flames," Proceedings of the Joint Technical Meeting 1993, Central and Eastern States Section of the Combustion Institute, New Orleans, LA, March 15-16, 1993.

Walter, P. and R. Edwards, "Nuclear Propulsion Control and Health Monitoring," Propulsion Engineering Research Center Fifth Annual Symposium, The Pennsylvania State University, University Park, PA, September 8-9, 1993.

Walter, P.B., and R.M. Edwards, "Comparison of CERMET and NERVA Nuclear Rockets with Classical and Advanced Controllers," to appear in Proceedings of the American Nuclear Society Topical Meeting on Nuclear Plant Instrumentation, Control and Man-Machine Interface Technologies, Oak Ridge, Tennessee, April 18-21, 1993.

Weiss, J. and C.L. Merkle, "Prediction of Engine and Near-Field Plume Reacting Flows in Low-Thrust Chemical Rockets," Paper No. AIAA-93-0237, 31st Aerospace Sciences Meeting & Exhibit, Reno, NV, January 11-14, 1993.

Wert, K. and H.R. Jacobs, "Effects of an Oscillatory Velocity Field on an Atomized Liquid Spray," Propulsion Engineering Research Center Fifth Annual Symposium, The Pennsylvania State University, University Park, PA, September 8-9, 1993.

Woodward, R., R. Burch, F.-B. Cheung, and K. Kuo, "Measurement of Intact-Liquid-Core-Length of and Spray Characteristics of Rocket Engine Coaxial Injectors," Propulsion Engineering Research Center Fifth Annual Symposium, The Pennsylvania State University, University Park, PA, September 8-9, 1993.

Yagley, J., J.-Z. Feng, and C. Merkle, "CFD Analyses of Coolant Channel Flowfields," Propulsion Engineering Research Center Fifth Annual Symposium, The Pennsylvania State University, University Park, PA, September 8-9, 1993.

Yagley, J., J. Feng, and C.L. Merkle, "CFD Analyses of Coolant Channel Flowfields," Paper No. AIAA-93-1830, 29th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, June 28-30, 1993, Monterey, CA.

Yang, A., K. Kuo, and W.-H. Hsieh, "Evaporation of LOX Under Supercritical and Subcritical Conditions," Propulsion Engineering Research Center Fifth Annual Symposium, The Pennsylvania State University, University Park, PA, September 8-9, 1993.

Yang, A.S., W.H. Hsieh, K.K. Kuo, and J.J. Brown, "Evaporation of LOX Under Supercritical and Subcritical Conditions," presented at the 29th AIAA/SAE/ASME/ASEE Joint Propulsion Conference and Exhibit, Monterey, CA, AIAA Paper No. 93-2188, June 28-30, 1993.

Yang, V., K.C. Hsieh, and J.S. Shuen, "Supercritical Droplet Combustion and Related Transport Phenomena," AIAA Paper No. 93-0812, AIAA 31st Aerospace Sciences Meeting, Reno, NV, January 1993.

Yeh, Y.P., F.B. Cheung, K.K. Kuo, and T.A. Litzinger, "Numerical Study of an Axisymmetric Turbulent Jet-Impingement Flow," Accepted for presentation at the 31st AIAA Aerospace Science Meeting, Reno, NV, January, 1993.

Zaccaria, M. D. Ristic, and B. Lakshminarayana, "Three-Dimensional Flow Field in a Turbine Nozzle, AIAA Paper No. 93-2556.

Zelesnik, D., M.M. Micci, and L.N. Long, "DSMC Simulation of Low Reynolds Number Nozzle Flows," AIAA Paper No. 93-2490, 29th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, June 28-30, 1993, Monterey, CA.

C.3 SPECIAL MENTIONS AND COMMUNITY SERVICE

Anderson, W. E.:

Local Chairman, First International Symposium on Liquid Rocket Combustion Instability, Penn State University, January, 1993.

Daines, R. S.:

NASA Graduate Student Research Program Scholarship Recipient

Dulikravich, G. S.:

Session Organizer and Chairman, Multidisciplinary Design Optimization, AIAA Aerospace Science Meeting, Reno, NV, January 11-14, 1993.

Foust, M.:

NASA Graduate Student Research Program Scholarship Recipient

Kuo, K. K.:

Chairman, Third International Symposium on Special Topics in Chemical Propulsion: *Non-Intrusive Combustion Diagnostics*, Scheveningen, The Netherlands, May 10-14, 1993.
Coordinator, AGARD/NATO Short Course, "Combustion of Solid Propellants," The Pennsylvania State University, September 21-22, 1993.

Lakshminarayana, B.:

Member, NASA Marshall Space Flight Center Turbine Technology Team
Member, NASA Marshall Space Flight Center Pump Technology Team
Member, AFOSR Military Aircraft Engine Advisory Group
Member, India-U.S. Joint Scientific Group in Aeronautics
Invited Keynote Speaker, TPMRC Colloquium on Turbomachinery 1993, Seoul, Korea
Chairman, Technical Session Propulsion Engineering Research Center 5th Annual Symposium

Merkle, C. L.:

Member of Seals Review Panel, NASA Lewis Research Center.
Member of NASA Space Propulsion Synergy Group.
Member of AIAA Liquid Propellant Technical Committee.
Associate Editor, Journal of Propulsion and Power, 1991-1994.
Co-Chairman, First International Symposium on Liquid Rocket Engine Combustion Instability, Penn State University, January, 1993.
ASME Best Paper Award, 29th Joint Propulsion Conference and Exhibit, Monterey, CA, June, 1993.

Micci, M. M.:

Member, AIAA Electric Propulsion Technical Committee

Oefelein, J.:

NASA Graduate Student Research Program Scholarship Recipient

C.3 SPECIAL MENTIONS AND COMMUNITY SERVICE (Continued)

Ondas, M.:

NASA Graduate Student Research Program Scholarship Recipient

Santavicca, D. A.:

Editorial Advisory Board Member, Combustion Science and Technology, 1992-1996.

Santoro, R. J.:

Member, NASA Microgravity Combustion Discipline Working Group, 1991-1993.
Member, Science Panel for Advanced Combustion Modules Conceptual Design Review, NASA Lewis Research Center, October 13-14, 1993.
Chairman, Eastern Section of the Combustion Institute, 1993-1995.
Mechanical Engineering Department Head's Outstanding Faculty Member, 1992-93.

Smith, G. A.:

Consultant to the P-15 Branch, Physics Division, Los Alamos National Laboratory, Los Alamos, NM on antiproton technology and applications.
Sabbatical leave, Phillips Laboratory, Kirtland AFB, Albuquerque, NM and Los Alamos National Laboratory, July 1, 1992-June 30, 1993.

Yang, V.:

Associate Editor, Journal of Propulsion and Power, 1991-1994.
Sabbatical at Princeton University and lecturer of graduate-level course on combustion instabilities in propulsion systems.
Chair of Technical Program Subcommittee, Propellants and Combustion Technical Committee, AIAA Aerospace Sciences Meeting, Reno, NV, January 1993.
Secretary, First International Symposium on Liquid Rocket Engine Combustion Instability, Penn State University, January, 1993.
Plenary Lecturer, National Conference on Combustion Science and Technology, Taiwan, March 1993.